UNIVERSITY OF TORONTO
3 1761 00532724 2

QB
465
B38
c.1

PASC

Digitized by the Internet Archive
in 2007 with funding from
Microsoft Corporation

http://www.archive.org/details/researchesonchem00baxauoft

SOLAR PHYSICS COMMITTEE.

RESEARCHES

ON THE

CHEMICAL ORIGIN OF VARIOUS LINES IN SOLAR AND STELLAR SPECTRA.

Being the Results of Investigations made at the Solar Physics Observatory, South Kensington, after discussion,

BY

FRANK E. BAXANDALL, A.R.C.Sc.,

First Assistant, Solar Physics Observatory.

UNDER THE DIRECTION OF

SIR NORMAN LOCKYER, K.C.B., LL.D., Sc.D., F.R.S.

LONDON:
PRINTED FOR HIS MAJESTY'S STATIONERY OFFICE,
BY EYRE AND SPOTTISWOODE, LTD.,
PRINTERS TO THE KING'S MOST EXCELLENT MAJESTY.

And to be purchased, either directly or through any Bookseller, from
WYMAN AND SONS, LTD., FETTER LANE, E.C.; or
OLIVER AND BOYD, TWEEDDALE COURT, EDINBURGH; or
E. PONSONBY, LTD., 116, GRAFTON STREET, DUBLIN.

1910.

Price Four Shillings and Sixpence.

12273
20/6/12

LIST OF PUBLICATIONS OF THE SOLAR PHYSICS COMMITTEE

FROM 1879 TO 1909.

	Year of Publication.
Preliminary Report of the Committee on Solar Physics	(1880)
Report by the Committee on Solar Physics	(1882)
Second Report by the Committee on Solar Physics	(1889)
Positions and Areas of Sun-Spots and Faculæ, 1887 and 1888	(1889)
,, ,, ,, ,, 1889	(1891)
,, ,, ,, ,, 1871-1881 (inclusive) and 1890 ...	(1892)
,, ,, ,, ,, 1891	(1894)
,, ,, ,, ,, 1892	(1895)
,, ,, ,, ,, 1893	(1896)
,, ,, ,, ,, 1894, 1895, 1896, and 1897 ...	(1899)
Spectra of Sun-Spots, 1879–1897 (inclusive)	(1900)
Positions and Areas of Sun-Spots and Faculæ, 1898 and 1899	(1901)
Catalogue of 470 of the Brighter Stars	(1902)
The Sun's Spotted Area, 1832–1900	(1902)
Positions and Areas of Sun-Spots and Faculæ, 1900, 1901, and 1902	(1904)
Mean Annual Variations of Barometric Pressure and Rainfall	(1905)
Positions and Areas of Sun-Spots and Faculæ, 1903 and 1904	(1906)
Tables of Wave-lengths of Enhanced Lines	(1906)
Spectroscopic Comparison of Metals present in certain Terrestrial and Celestial Light Sources (with special reference to Vanadium and Titanium)	(1907)
Report of the Solar Eclipse Expedition to Palma, Majorca, August 30th, 1905 ...	(1907)
Positions and Areas of Sun-Spots and Faculæ, 1905	(1907)
Monthly Mean Values of Barometric Pressure for 73 Selected Stations over the Earth's Surface	(1908)
On the General Spectra of certain Type-Stars and the Spectra of several of the Brighter Stars in the Green Region	(1908)
Positions and Areas of Sun Spots and Faculæ, 1906	(1909)
A Discussion of Australian Meteorology	(1909)

QB
465
B38

CONTENTS.

PAGE

Preface - - - - - - - - - iv

General Introduction - - - - - - - v

I.

The Spectra of the Sun (Fraunhoferic) Chromosphere, and Lower-type Stars in relation to the Sun-Spot Spectrum - 1

Comparison of Solar (Fraunhoferic) and Capellan Spectra - - - - - 1

Table showing lines affected in passing from the Solar Spectrum to that of Capella - - - - - - - - 2

Comparison of the Spectra of the Sun (Fraunhoferic), Sun-Spots, and Arcturus - - - - - - - - 4

Lines which are affected in passing from the Fraunhoferic Spectrum to that of Arcturus - - - - - - - - 5

Comparison of the affected Arcturus lines in the Kensington and Mount Wilson records - - - - - - - - 11

Physical Relationship of the vapours in Sun-Spots, the Solar Photosphere, and the absorbing atmosphere of Arcturian Stars - - - - - - - - 22

Comparison of Solar Spectrum and Spectra of Secchi's third type - - 24

Tables of lines strengthened in passing from Solar Spectrum to Secchi's third type - - - - - - - - 27

Relation of fourth-type stars to those of the third type and Arcturus - - 9

Relation of the Chromospheric Spectrum to those of the Sun (Fraunhoferic) Sun-Spots and lower-type stars - - 29

II.

The Spectrum of ε Ursæ Majoris 31

Introduction - - - - - - - 31

Wave-lengths, intensities, and probable origins of lines in the Spectrum of ε Ursæ Majoris - - - - - 31

Comparison of the Spectra of ε Ursæ Majoris and Sirius - - - - - 44

Table showing the most marked differences in the Spectra of ε Ursæ Majoris and Sirius - - - - - - - 44

Analysis of the origins of lines affected in passing from ε Ursæ Majoris to Sirius 48

Table showing the relative intensities of proto-chromium lines in the Spectra of ε Ursæ Majoris, Sirius, and α Cygni - 49

PAGE

Comparison of the Kensington negatives of ε Ursæ Majoris - - - - - 50

Position of ε Ursæ Majoris in the Stellar classification - - - - - - 50

General Conclusions - - - - - 51

III.

Nitrogen lines in Stellar Spectra - 52

Table showing the relative intensities of the strongest lines of Nitrogen in the Spectra of Rigel, Bellatrix, κ Orionis, ε Orionis, ζ Orionis, and ι Orionis - 56

IV.

Second List of Enhanced Lines - - 58

Introduction - - - - - - 58

Tables of Enhanced Lines - - - - 58

Arsenic - - - - - - - 58

Barium - - - - - - - 59

Beryllium - - - - - - - 59

Cadmium - - - - - - - 59

Cerium - - - - - - - 59

Gold - - - - - - - - 60

Iridium - - - - - - - 60

Lithium - - - - - - - 60

Platinum - - - - - - - 61

Selenium - - - - - - - 62

Tellurium - - - - - - - 63

Tungsten - - - - - - - 64

V.

Lines of simple and definite origin suitable for measurement in radial velocity work on various stellar types - - 65

Introduction - - - - - - 65

Tables giving wave-lengths and origins of selected lines for various stellar types - - - - - - - - 66

VI.

Lines of unknown origin in various Celestial Spectra - - - - - - 71

Introduction - - - - - - 71

Table of fairly prominent lines in Celestial Spectra for which no terrestrial origin is known - - - - - - - - 73

a (11)4973. Wt. 9545. 400. 10/10. E. & S.

PREFACE.

During the last few years various researches have been undertaken here, the results of some of which have from time to time been published by the Solar Physics Committee. Others have been held over for various reasons, and the present publication consists of those which have now been completed.

The researches all have to do with the determination of wave-lengths and origins of lines photographed in stellar, solar, or laboratory spectra, and subsequent discussion of the results and inter-relation of the lines in the various spectra. This work has been carried out by Mr. Baxandall, and the memoir written by him. He has also written an introduction.

The laboratory and solar spectra involved in the discussion have been photographed chiefly by Mr. Butler. The stellar photographs used have been obtained by various members of the staff.

Solar Physics Observatory,
10 *June* 1910.

NORMAN LOCKYER.

GENERAL INTRODUCTION.

Although six distinct papers are included under separate headings, it has been thought best to publish them in one volume under the general heading "Researches on the Chemical Origin of various Lines in Solar and Stellar Spectra" rather than as separate publications.

Part I., gives the results of a comparative study of the spectra of the sun (Fraunhoferic) chromosphere, and lower-type stars in relation to the sun-spot spectrum. This work was initiated some seven years ago, and in the meantime several papers have been published from Mount Wilson Observatory bearing on the same subject. These are referred to in the text, and a comparison made of the Mount Wilson and Kensington results.

In this comparative study the stellar spectra dealt with in detail are Capella and Arcturus.

The former is, in the main, very similar to the Fraunhoferic spectrum. Whatever differences there are have been indicated in the paper.

The spectrum of Arcturus has been found to approximate very closely to that of a sun-spot, the chief lines strengthened in passing from the Fraunhoferic spectrum to the Arcturian spectrum being lines of vanadium and titanium, which are also much strengthened in sun-spot spectra. The physical relationship of the vapours in sun-spots, the solar photosphere, and the absorbing atmospheres of Arcturian stars have been discussed, and the conclusion come to that the vapours in the stellar atmosphere and those of a sun-spot are probably subject to nearly identical conditions of temperature or electrical excitation, and that the temperature in each of these cases is lower than the mean temperature of the vapours of the solar photosphere.

Part II. contains the results of an investigation of the spectra of ϵ Ursæ Majoris, which is a star of the Sirian type, but showing peculiarities in its spectrum as compared with the normal Sirian spectrum. The wave-lengths, intensities, and probable origins of the lines have been determined, and the most marked differences between its spectrum and that of Sirius have been denoted. One of the chief results obtained is that the lines of proto-chromium are more pronounced in the spectrum of ϵ Ursæ Majoris than in that of any other star whose spectrum has been obtained with sufficient dispersion as to allow of its being efficiently examined in detail. It does not follow from this that there is a larger proportion of chromium vapour in the atmosphere of ϵ Ursæ Majoris than in other stellar atmospheres, the more probable explanation being that the particular temperature or state of electrical excitation of the vapours in ϵ Ursæ Majoris is more conducive to the existence of the proto-chromium lines than in the case of other stars.

Part III. contains a discussion of the occurrence of nitrogen lines in stellar spectra. Although various observers have mentioned the presence of certain lines of nitrogen in the spectra of various stars, nothing approaching a complete statement has been given, and the present paper gives the relative intensities of all the stronger nitrogen lines in the spectra of Rigel, Bellatrix, κ, ϵ, ζ, and ι Orionis. In types of stellar spectra below the Rigelian (Rigel) stage and above the Alnitamian (ι Orionis) stage no nitrogen lines occur.

Part IV. contains lists of enhanced lines of some of the metals which were not included in the previous publication* on the same subject, but which have since become available. These are arsenic, barium, beryllium, cadmium, cerium, gold, iridium, lithium, platinum, selenium, tellurium and tungsten.

Part V. consists of tables of wave-lengths of stellar lines of simple and definite origin suitable for measurement in radial velocity work on various stellar types.

Part VI.—In various celestial spectra there is a residuum of well-marked lines for which no terrestrial equivalents have yet been found. These are here brought together and arranged in order of wave-length. The particular celestial source of each line is indicated in the table and the intensity in its particular spectrum also given. This list of unknown celestial lines should be useful to refer to in the event of strange lines occurring in laboratory spectra, with the view of tracing the identity of some of the celestial lines.

* "Tables of Wave-lengths of Enhanced Lines." (Published by the Solar Physics Committee.)

I.

THE SPECTRA OF THE SUN (FRAUNHOFERIC), CHROMOSPHERE, AND LOWER-TYPE STARS, IN RELATION TO THE SUN-SPOT SPECTRUM.

In the Kensington classification of stellar spectra embodied in a previous publication,* the Sun was considered to be a star whose spectrum conforms more closely to that of the type star of the Arcturian Group (Arcturus) than to that of any of the other main groups into which the stars were divided.

No subdivision of the various groups was attempted, but in the case of the Sun it has been thought desirable to compare carefully its spectrum with those of the brighter stars in the Arcturian Group, with the object of determining—by a detailed study of any difference in the relative intensity of its lines from those of the other Arcturian stars—its true position in the group.

It has generally been accepted by the various workers in the subject that, of stellar spectra, that of Capella most nearly resembles the solar spectrum. Comparison was therefore first made between the solar spectrum and that of Capella.

The photographs employed for the comparison were obtained with a 6-inch objective and two 6-inch Henry prisms of 45° angle, a collimator being introduced in the case of the solar spectrum. The dispersion given is such that the distance between K. and F. on the photographic plate is 3·8 inches (96 mm.).

COMPARISON OF SOLAR (FRAUNHOFERIC) AND CAPELLAN SPECTRA.

The lines in the solar photograph—owing to the use of a slit—are naturally sharper than in the stellar one, and the solar groups of lines are more easily resolvable into their individual lines than the corresponding groups in the stellar spectrum. The comparison which can be made, however, is quite good enough to show the chief modifications which occur with regard to the lines in passing from one spectrum to the other. It has been found that the great majority of the lines and groups of lines are identical in the two spectra, both in regard to position and relative intensity.

The chief differences are given in the following table. When two or more lines are bracketed together in the first column, it denotes that the individual lines cannot be separated in the stellar spectrum, and the remarks as to strengthening or weakening refer to the relative intensity of the lines collectively as they occur in Sun and star.

* "Catalogue of 470 of the Brighter Stars." (Published by the Solar Physics Committee.)

LINES AFFECTED IN PASSING FROM THE SOLAR SPECTRUM TO THAT OF CAPELLA.

λ of Solar Lines (Rowland).	Probable Origin (Un = Unknown).	Whether strengthened or weakened in Capella.
1066·5	Co.	Collectively strengthened.
·7	Fe.	
7·1	Fe.	
·4	Fe.	
4077·9	p Sr.	Slightly strengthened.
4083·8	Mn.	Weakened.
·9	Fe.	
4084·6	Fe.	Weakened.
4105·1	Un.	Strengthened.
·3	V.	
4118·7	Fe.	Slightly strengthened.
·9	Co.	
9·0	Fe.	
4129·3	Ce.	Slightly strengthened.
·6	Un.	
30·2	Fe.	
4137·2	Fe.	Strengthened.
4146·2	Fe.	Weakened.
4147·5	Un.	Weakened.
·6	Mn.	
·8	Fe.	
4157·9	Fe.	Weakened.
4159·4	Un.	Much weakened or lacking.
4163·9	p Ti.	Strengthened.
4165·6	Fe.	Weakened.
4171·1	Fe.	Very much weakened.
·2	p Ti.	
4173·5	Fe.	Strengthened.
·6	p Fe.	
·7	p Ti.	
4175·1	Fe.	Weakened.
4175·8	Fe.	Weakened.
4176·8	Fe.	Weakened.
4188·9	Un.	Weakened.
4199·2	Fe. Sr.	Weakened.
200·1	Fe.	
0·6	Ni.	
0·9	Ti.	
1·1	Fe.	
4215·6	Fe.	Strengthened.
·7	p Sr.	
4245·4	Fe.	Slightly weakened.
·5	Un.	
4289·9	Cr.	Strengthened.
90·1	Ti.	
0·4	p Ti.	
4295·2	Un.	Weakened.
·4		
4318·8	Ca. Mn.	These two (treating the close double as one) have about the same intensity in the Sun; the second is in Capella much the stronger.
4320·9	Sc.	
1·1	p Ti.	
4325·9	Fe.	In the Sun Fe. 4325·9 is slightly stronger than Hγ, in Capella it is slightly weaker.
4340·6	Hγ.	
4369·9	Fe.	Weakened.
4371·1	Fe.	Slightly weakened.
·2	Un.	
·4	Cr.	
4374·6	Sc. Fe.?	Strengthened.
5·1	V. Mn. Y.	
4376·1	Fe.	Weakened.
4407·8	V.	Strengthened.
·9	Fe.	
8·4	V.	
·6	Fe.	
·7	V.	
4441·0	p Ti.	Strengthened.
·6	V. Ti	
·7	Fe. Ti.	
4455·0	Ca.	Slightly weakened.
4469·5	Fe.	Strengthened.
·7	Co.	
·9	V.	
4479·6	Mn.	Strengthened.
9·8	Fe.	
·9	Ti.	
4481·3	? p Mg.	Weakened.
·4	Ti.	
4498·9	Cr.	Weakened.
9·1	Mn.	

λ of Solar Lines (Rowland).	Probable Origin (Un = Unknown).	Whether strengthened or weakened in Capella.
4501·4	p Ti.	Strengthened.
4508·5	p Fe.	Slightly strengthened.
4522·8	p Fe.	Slightly strengthened.
3·0	Ti.	
4525·3	Fe.	Slightly weakened.
4529·7	Un.	Slightly weakened.
·7	Un.	
·8	Fe.	
30·0	Cr.	
4574·4	Fe.	Slightly strengthened.
·9		
4584·0	p Fe.	Slightly strengthened.
4607·5	Sr.	Slightly weakened.
·8	Fe.	
4646·3	Cr.	Strengthened.
·8	Un.	
7·0	Cr.	
4656·6	Ti.	Strengthened.
7·2	Un.	
·4	Ti. ?	
4691·5	Ti.	Weakened.
·6	Fe.	
4698·6	Co.	Strengthened.
·6	Cr.	
·8	Cr.	
·9	Ti.	
4703·2	Mg.	Weakened.

The comparison affords little or no evidence of any marked difference in the temperature conditions of the absorbing vapours of Capella and the Sun. The strong arc lines of iron, such as the triplets at 4045 to 4072 and 4383 to 4415, are, in Capella, a little less outstanding than in the Sun, and from this it would appear that the latter should be placed a little below Capella on the temperature scale, as the iron arc lines gradually thin out in passing from the Piscian through the intermediate Arcturian and Procyonian stages to those of the Sirian and higher groups.

The variation in intensity of other lines also points to the Sun being a little lower than Capella. The solar group $\left\{\begin{matrix} 4318{\cdot}8 & \text{Ca. Mn.} \\ 4320{\cdot}9 & \text{Sc.} \\ 4321{\cdot}1 & \text{p Ti.} \end{matrix}\right\}$ for instance is modified in the Capellan spectrum. These two lines (treating the close solar double as one) have about the same intensity in the Sun, while in Capella the second is considerably stronger than the first. The stronger Capella line, due partly to scandium and partly to proto-titanium, is still more developed at the Procyonian stage, which is undoubtedly higher than the solar stage, so from the behaviour of this line alone Capella is an intermediate stage between the Sun and Procyon, but much nearer the former than the latter.

The majority of the enhanced lines of iron and titanium, which show any change at all in the stellar spectrum, seem to be slightly strengthened, and these are still further strengthened in passing from the Capella to the Procyonian stage.

COMPARISON OF THE SPECTRA OF THE SUN (FRAUNHOFERIC), SUN-SPOTS, AND ARCTURUS.

In a previous note to the Royal Society "On the Relation between the Spectra of Sun-Spots and Stars,"* it was pointed out that the spectrum of Arcturus, unlike that of Capella, showed many variations from the solar spectrum, especially in regard to the relative intensities of some of the lines. One of the general conclusions established from a detailed comparison of the two spectra was that, in the case of the majority of the lines much strengthened in Arcturus, either vanadium or titanium was involved in the origin. These results were obtained from a direct comparison of an Arcturus spectrum taken with two 6-inch Henry prisms of 45° angle, and a solar spectrum photographed with the same prisms provided with a collimator.

It was intended at the time to publish a detailed account of the comparison which had been made, but other work has prevented this. In the meantime two papers have been published by Mr. Adams, of Mount Wilson Observatory, bearing closely on the same subject. The first one was entitled "Sun-Spot Lines in the Spectrum of Arcturus,"† in which is given a tabular comparison of solar lines affected in the spectra of Sun-Spots and Arcturus in the region extending from λ4352·91 to λ4900·10. Adams' second paper is a "Preliminary Catalogue of Lines Affected in Sun-Spots" (Region λ4000 to λ4500).‡

As the region of the Arcturus spectrum investigated at Kensington extends from λ3989 to λ4900, whereas the comparison of Arcturus and Sun-spot lines by Adams was limited to the region λ4353 to λ4900, no comparison could be made between the two records in the part of the spectrum from λ3989 to λ4353. In Adams' later paper, on affected lines in Sun-spot spectra, however, the region λ4000 to λ4353 is included, so that the lines showing alterations of intensity in the Kensington spectra in passing from the Sun to Arcturus can be compared with the affected lines in Sun-spots as recorded by Adams. This has been done in the following table. Under the heading "Sun-Spot Lines" (Mount Wilson) only those lines have been included which correspond with lines or group of lines which have been found to be affected in the Kensington Arcturus spectrum. A glance at the table will show that in nearly all cases the lines found strengthened in the Kensington Arcturus spectrum are strengthened in Adams' Sun-Spot spectra, and also that weakened lines in the one are weakened in the other. This amply confirms Adams' conclusions with regard to what happens in the region λ4353 to λ4900, which he had previously compared.

* Roy. Soc. Proc., vol. 74, p. 53. † Ast. Phys. Jour., vol. 24, p. 69, 1906.
‡ Ast. Phys. Jour., vol. 27, p. 45, 1908.

LINES WHICH ARE AFFECTED IN PASSING FROM THE FRAUNHOFERIC SPECTRUM TO THAT OF ARCTURUS.

(Region 3990 to 4353.)

Solar Lines λ (Rowland).	Origin.	Remarks on Variation in Intensity from Sun to Arcturus. (Kensington.)	Sun-Spot Lines. (Mount Wilson.) λ	Intensity. (Higher Numbers represent Higher Intensities.) Sun.	Spot.
3989·9	Ti.	Strengthened.	Beyond the region investigated by Adams.		
90·1	Fe.				
3998·8	Ti.	Considerably strengthened.			
4015·7	p Ni.	Slightly weakened.	4015·76	3	2
4019·2	Ni. Ce.	Strengthened.	4019·20	1	1–2
4024·7	Ti.	Collectively strengthened.	4024·73	3	4
·9	Fe.		4025·16	0	4
5·3	Ti.		5·29	3	
4026·6	Mn.	Strengthened.	4026·58	2	4
·7	Ti.		·69	1	
4042·7	Cr. Nd.	Very weak in Sun. Strengthened in Arcturus.			
4044·8	Fe.	Weakened.			
4051·5	Cr. V.	Weak in Sun. Stronger in Arcturus.	4051·49	0	0–1
4055·0	Un.	Strengthened.	4054·96	2	4
·0	Fe.		5·02	3	
·2	Ti. Fe.				
4055·7	Mn.	Weakened.	4055·70	6	7
4064·4	Ti.	Considerably strengthened.	4064·36	1	2
·5	Ni.				
·6	Fe.				
4069·2	Un.	Much strengthened.			
4076·1	Fe.	Strengthened.	4076·10	3	2–3
·4	Fe. Ce.				
4078·5	Fe.	Slightly strengthened.	4078·52	4	8
·6	Ti.		·63	3	
4082·3	Fe.	Considerably strengthened.	4082·26	2	2–3
·6	Fe. Sc. Ti.		4082·59	3	4
4090·7	V.	Much strengthened.	4090·73	1	2
4092·4	Fe.	Strengthened.			
·5	Co. Mn.				
·8	V.		4092·82	3	4–5
4099·9	V.	Considerably strengthened.	4099·94	2	4

Solar Lines λ (Rowland).	Origin.	Remarks on Variation in Intensity from Sun to Arcturus. (Kensington.)	Sun-Spot Lines. (Mount Wilson.) λ	Intensity. (Higher Numbers represent Higher Intensities.) Sun.	Spot.
4100·9	Fe.	Strengthened.	4100·90	4	4–5
4102·0	H.	Hδ. Weakened.	4102·00	40	20
4104·3	Fe.	Considerably strengthened. The intensification seems to be on the less refrangible side, and is probably chiefly due to V.			
·6	V.				
4105·3	V.	Considerably strengthened.	4105·32	2	4
4108·7	Un.	,, ,,	4108·69	2	3
4109·9	V.	Considerably strengthened. The intensification seems to be on the more refrangible side of the solar double, and is therefore probably chiefly due to V.	4109·90	2	7
10·0	Fe.		·95	3	
4111·9	V.	Considerably strengthened.	4111·94	4	6
4113·1	Fe.	Weakened.	4113·07	1	3
			·12	3	
4114·6	Fe.	Well-marked line in Sun. Nearly evanescent in star.	4114·61	4	5
4116·6	V.	Much strengthened.	4116·63	1	3–4
·7	V.		16·71	0	
·9	Nd.?		4116·97	00	0
4121·4	Cr. Co.	Slightly strengthened.	4121·48	6	7
·9	Fe. Cr.				
4122·7	Fe.	Much weakened.	4122·82	1	1–2
·8	Un.				
4123·5	V.	Considerably strengthened.	4123·54	0	3–4
·7	Mn.		·66	1	
			·71	000	
4127·8	Fe.	These lines are inseparable in Arcturus. The stellar line is, however, strongest on the less refrangible side, whereas the solar group seems strongest on the more refrangible side. This is doubtless owing to the relatively increased intensity of the V lines in the star.			
8·0	Fe.				
·3	V.		4128·25	6	8
4129·9	Un.	Strengthened.	4130·11	0	3
30·1	Un.		·20	2	
·2	Fe.				
4133·8	Fe.	Weakened.	4133·76	2	0
4·0	Fe.				
4137·2	Fe.	Strengthened.	4137·16	6	7
·4	Ti. Mn.		4137·43	0	3–4
·6	Un.		·57	2	

Solar Lines λ (Rowland).	Origin.	Remarks on Variation in Intensity from Sun to Arcturus. (Kensington.)	Sun-Spot Lines. (Mount Wilson.) λ	Intensity. (Higher Numbers represent Higher Intensities.) Sun.	Spot.
4140·6	Un.	Slightly strengthened.	4140·56	3	3–4
4142·0	Fe.	Much strengthened.	4142·02	4	4–5
4152·1	Fe. La.	Slightly strengthened.	4152·24	1	4–5
·3	Fe.		·34	3	
4159·0	Fe.	Much weakened.			
·4	Un.		4159·35	5	4
4162·6	Un.	Weakened.	4162·62	1	0–1
·8			·82	1	0–1
4163·8	Cr. p Ti.	Slightly weakened.	4163·82	4	3–4
4165·6	Fe.	Strengthened.	4165·55	3	2–3
·8	Ce.		4165·76	1	0–1
4167·4	Un.	Weakened.	4167·44	8	6
4168·0	Un.	Strengthened.	4168·02	2	4–5
·1	Ni.		·13	2	
4171·1	Fe.	Considerably weakened.	4171·07	4	4–5
·2	Ti.				
4171·8	? Fe.	Collectively considerably strengthened.	4171·85	2	2–3
2·1	p Ti. Fe.		2·07	2	1–2
·2	Al. ?		·21	1	4–5
·3	Fe.		·30	2	
4175·8	Fe.	Slightly weakened.	4175·81	5	5-6
4176·7	Fe. Mn.	Weakened.			
4179·0	p Fe.	Slightly weakened.	4179·02	3	2
·5	V.				
4181·7	Un.	Weakened.			
·9	Fe.		4181·92	5	5–6
2·1	Un.		4182·14	2	1–2
4186·3	Ti.	Considerably strengthened.	4186·28	1	2
4187·2	Fe.	Slightly strengthened.	4187·20	6	7
4187·9	Fe.	" "	4187·94	5	9
8·0	Un.		8·02	3	
4190·0	V.	Very weak in Sun. Much stronger in Arcturus.	4189·98	0	1
4190·9	Co.	Very weak in Sun. Stronger in Arcturus.	4190·87	1	2–3
4193·8	Cr.	Strengthened.			
4199·3	Fe. Zr.	Weakened.	4199·27	5	6
4204·1	Fe.	Slightly weakened.			
·2	La.				

Solar Lines λ (Rowland).	Origin.	Remarks on Variation in Intensity from Sun to Arcturus. (Kensington.)	Sun-Spot Lines. (Mount Wilson.) λ	Intensity. (Higher Numbers represent Higher Intensities.) Sun.	Spot.
4204·9 5·2 ·2	Un.	Much strengthened.	4204·88 ·92	1 2	2
4206·7 ·9	Un. Fe.	Strengthened.	4206·74 ·86	1 3	5
4210·0	V.	Very much strengthened.	4209·98	1	2
4210·5 ·6	Fe. Un.	Slightly strengthened.	4210·49 ·56	4 3	8–9
4211·1	Un.	Weakened.	4211·13	3	2–3
4212·0	Zr.	Slightly weakened.	4212·05	2	1
4212·8	Un.	Slightly strengthened.			
4213·8	Fe.	Much broader and hazier in Arcturus.	4213·81	3	3–4
4216·4	Fe.	Considerably strengthened.	4216·35	3	4–5
4225·6	Fe.	Strengthened.	4225·62	3	3–4
4226·9	Ca.	Considerably strengthened.	4226·90	20	25
4229·7 ·9	Fe.	Slightly strengthened.	4229·68 ·93	2 3	2·3 4
4231·2	Ni.	Very weak or lacking in Arcturus.			
4232·8 ·9 3·1	V. Fe. V.	Much strengthened.	4232·76 ·89	00 2	3–4
4233·3	p Fe.	Weakened.	4233·33	4	3
4234·2	Co.V.	Considerably strengthened.	4234·17	0	0–1
4235·3 ·5	Mn.	Slightly weakened.	4235·30 ·45	2 3	6
4239·9 40·0	Mn. Fe.	Slightly strengthened.	4239·89 40·01 ·12	3 3 1	9
4247·0	Sc.	Strengthened.	4247·00	5	6
4247·6	Fe.	Slightly weakened.	4247·46 ·59	1 4	6
4254·5	Cr.	Strengthened.	4254·50	8	10
4255·1 ·4 ·7 ·8 6·0 ·3 ·4	Fe. Un. Fe.-Cr. Un. Fe. Ti. Un.	These lines form in the Sun a rather weak broad cluster. In Arcturus there seems to be little or nothing corresponding to the first four. There is, however, quite an outstanding line which embraces the position of the latter three lines. Which solar line is intensified in Arcturus it is impossible to say.	4255·66 ·79 4256·29 ·37	1 1 0 1	2–3 2–3

Solar Lines λ (Rowland).	Origin.	Remarks on Variation in Intensity from Sun to Arcturus. (Kensington.)	Sun-Spot Lines. (Mount Wilson.) λ	Intensity (Higher Numbers represent Higher Intensities.) Sun.	Spot.
4258·3	Un.	Strengthened.	4258·32	1	0–1
·5	Fe.		·48	2	4
4274·7	Ti.	Strengthened.	4274·75	2	12
5·0	Cr.		·96	7	
4276·8	Zr.	Very weak in Sun. Well shown in Arcturus.	4277·15	1	1–2
7·1	V.				
4277·7	Un.	Strengthened.	4277·69	2	3
4279·6 to 4281·3	Chiefly Unknown.	Broad bunch of individually weak lines in Sun. Collectively strengthened in Arcturus. Local intensification near 4280·1.	4279·87	2	1
			80·56	1	2
			·94	1	0–1
			1·26	2	2–3
4282·6	Fe.	Strengthened.	4282·56	5	6
3·2	Ca.		3·17	4	5–6
4284·2	Mn.V.	Strengthened.	4284·22	0	0–1
·4	Un.		4284·38	2	1
4286·2	Ti.	Strengthened.	4286·17	2	3–4
4289·9	Cr.	Strengthened.	4289·88	5	8
0·1	Ti.		90·08	1	
4293·2	Un.	Weakened.	4293·19	2	4
·3			·27	3	
4294·2	Ti.	Slightly strengthened.	4294·20	2	9
·3	Fe.		·30	5	
4295·9	Cr. Ti.	Strengthened.	4295·91	2	3–4
4296·7 to 4297·4	p Fe. Cr. and Un.	Weakened.	4296·74	3	3
			·84	1	
			7·37	2	3
			·45	2	
4298·8	Ti.	Collectively strengthened.	4298·83	2	3
9·0	Un.		·97	2	1
·1	Ca.		9·15	3	4
·4	Ti. Fe.		·41	4	5
4300·2	p Ti.	Weakened.	4300·21	3	2–3
4302·1	Ti.	Strengthened. The intensification seems to be greatest on the more refrangible side.	4302·08	2	1–2
·4	Fe.				
·5	Un.				
4306·1	Ti.	Strengthened.	4306·08	4	5–6
4306·9	Un.	Very weak or lacking in Arcturus.	4306·86	2	3
7·0			7·02	2	
4309·5 to 4309·9	Fe. and Un.	Collectively strengthened.	4309·54	3	3–4
			·79	1	1
			·88	1	

Solar Lines λ (Rowland).	Origin.	Remarks on Variation in Intensity from Sun to Arcturus. (Kensington.)	Sun-Spot Lines. (Mount Wilson.) λ	Intensity. (Higher Numbers represent Higher Intensities.) Sun.	Spot.
4313·0	p Ti.	Slightly strengthened.	4313·03	3	2–3
4315·0	Ti.	Much strengthened.	4314·96	1	2–3
·1	p Ti.		5·14	3	8
·3	Fe.		·26	4	
4317·0	Ti. ?	Strengthened.	4316·96	1	0–1
4320·9	Sc.	Slightly strengthened.			
1·1	p Ti.		4321·12	2	1–2
4325·2	Sc.	Slightly strengthened.	4325·15	4	6
·3	Ti. Cr.		·31	1	
4328·1	Fe.	Slightly strengthened.	4328·08	2	2 3
4330·2	V.	Much strengthened.	4330·19	0	2
·4	Un.		4330·40	1	0
4332·7	Un.	Strengthened.			
3·0	V.		4332·99	0	1–2
·1	Un.		3·08	0	
4333·9	La.	Weak in Sun. Stronger in Arcturus.			
4334·8	Un.	Weak narrow solar group. Strengthened in Arcturus.			
5·0	Un.				
·1	La.		4335·10	0	1
4377·6	Cr.	Strengthened, the intensification being more marked on the more refrangible edge of the stellar line.	4337·72	3	4–5
8·1	p Ti.		8·08	4	3
·4	Fe.		·43	1	2
4339·6	Cr.	Strengthened.	4339·62	4	6
·9	Cr.		4339·88	3	4
4340·6	H.	Hγ weakened.	4340·63	20	8
4343·4	Fe. Cr.	Strengthened.	4343·37	2	4–5
				2	
4344·5	Ti.	Strengthened.	4344·45	2	1-2
·7	Cr.		4344·67	4	6
4346·7	Fe.	Strengthened.			
7·0	Cr.		4346·99	1	1–2
4348·0	Fe.	Considerably strengthened.			
·5	Un.		4348·50	1	0–1
4351·0	Ti.	Considerably strengthened.	4351·00	1	0–1
·2	Cr.		4351·22	3	5

COMPARISON OF THE AFFECTED ARCTURUS LINES IN THE KENSINGTON AND MOUNT WILSON RECORDS.

In Adams' paper on "Sun-Spot Lines in the Spectrum of Arcturus"* it was most distinctly shown that the strengthened lines in sun-spots are in the great majority of cases also strengthened in Arcturus. Another point elicited from the investigation is that lines of vanadium and titanium figure prominently amongst the most strengthened lines.

It has been thought desirable to compare in detail the Kensington record (Sun and Arcturus) with that of Adams (Sun-Spot and Arcturus) in the region where they cover common ground. It may be said at once that for the majority of the lines the two records agree. There, is however, a number of lines which occur only in one or other of the lists. As the dispersion of the Mount Wilson photographs is about two and a half times that of the Kensington spectra, it is only to be expected that Adams would be able to separate the stellar lines better, and give a more complete record; nevertheless it seemed desirable that the Kensington photographs should be re-examined with the object of ascertaining whether some of the extra lines given by Adams had been inadvertently missed, or whether the lower dispersion available had made it impossible to separate such lines from adjoining ones. This has been done and the results incorporated in the following comparison table.

The first column of the table contains the wave-lengths (from Rowland's solar tables) of the solar lines involved. The second column gives the probable origins of these lines. Rowland's origins have been used as a basis, but these have been supplemented by reference to the Kensington lists of enhanced lines. A number of solar lines, undoubtedly due to these, were left unorigined by Rowland. The third column shows the behaviour of the lines in the Arcturus spectrum. Such terms as "weakened," "strengthened," "much strengthened," &c., have been preferred to numbered intensities, owing to the fact that in many cases the stellar lines consist of two or more solar lines blended together. The fourth, fifth, sixth and seventh columns give Adams' wave-lengths, origins, "intensity in sun," and "intensity in star" respectively. The last column is reserved for remarks, chiefly on the behaviour of Adams' extra lines in the Kensington photograph of the Arcturus spectrum.

* Ast. Phys. Jour., vol. 24, p. 69, 1906.

COMPARISON OF THE AFFECTED ARCTURUS LINES IN THE KENSINGTON AND MOUNT WILSON RECORDS.

Kensington.			Mount Wilson				
λ of Solar Lines.	Probable Origin. Un. = Unknown.	Behaviour in Arcturus Spectrum.	λ of Solar Lines.	Origin.	Intensity. Sun.	Intensity. Star.	Remarks. (K.S. = Kensington Spectrum.)
4353·0	Fe.	Strengthened.					
			4355·26	Ca ?	2	3	Combined with 4354·8, slightly strengthened in K.S.
			4356·06		0	2	Combined with 4355·9, slightly strengthened in K.S.
			·16	Ni.	0		
4360·5	Un.	Strengthened.					
·6	Ti.						
61·0	Zr.						
4363·6	Un.	Much strengthened.	4363·63		0	2	
·7			·77		0		
4367·7	Fe.	Considerably strengthened.	4367·75	Fe.	5	*	* Not changed.
·8	Ti.		·84	Ti.	2		
8·1	Fe.						
			4371·14	Zr.	1	6	Little strengthened, if any, in K.S.
			·22		1		
			·32		00		
			·44	Cr.	2		
			4372·50		0	1	Cannot be seen in K.S., either of sun or star.
			4373·42	Cr.	1	2	Combined with 4373·7 strengthened in K.S.
4375·7	Un.	Considerably strengthened.					
·8	Un.						
6·1	Fe.						
4379·4	V.	Strengthened.					
4384·9	V.	Considerably strengthened.					
5·1	Cr.						
·3	Un.						
·4	La.						
·5	p Fe.						
4390·1	V.	Slightly strengthened.					
			4391·82	Co.	0	5	
			·92	Cr.	1		
			2·03	Co.	0		
4392·2	V ?	Slightly strengthened.	·24	V ?	1		
			4393·20	V.	0	0–1	Cannot isolate this weak line in K.S.
4395·2	Ti.	Much strengthened.	4395·20	Ti.	3	7	
·4	V. Zr.		·41	V. Zr.	2		
4396·1	Ti.	Weakened.					

Kensington.			Mount Wilson.				Remarks. (K.S. = Kensington Spectrum.)
λ of Solar Lines.	Probable Origin. Un. = Unknown.	Behaviour in Arcturus Spectrum.	λ of Solar Lines.	Origin.	Intensity. Sun.	Intensity. Star.	
4397·1	Un.	Weakened.					
4398·2	? Y.	Slightly strengthened.					
4400·6	Sc.	Considerably strengthened.					
·7	V.		4400·74	V.	1	3	
4404·9	Fe.	Slightly strengthened.					
			4406·81	V.	2	5	Not strengthened in K.S.
			4407·81	V.	2	7	Not strengthened in K.S.
			·87	Fe.	4		
4408·4	V.	Considerably strengthened.	4408·36	V.	2	3	
·6	Fe.		·58	Fe.	3	6	
·7	V.		·68	V.	2		
4409·3	Fe ?	Strengthened.					
·4	Un.						
4412·3	V.	Very much strengthened.	4412·30	V.	00	4	
·4	Cr.		·43	Cr.	0		
4415·3	Fe.	Slightly strengthened.					
			4416·64	V.	0	3	Inseparable in K.S. Combined line not strengthened.
			4416·98	p Fe.	2	1	
			4417·45	Ti.	0	3	Inseparable from p Ti. 4417·8 in K.S. Collectively not strengthened.
			·58	Co.	00		
			4419·94	Mn.	00	1	Slightly strengthened in K.S.
			20·10	V.	00		
4421·7	V.	Much strengthened.					
2·1	Un.						
2·2	Un.						
4422·7	Fe.	Much strengthened.					
3·0	Ti.						
3·3	Fe.		4423·30	Fe.	1	2–3	
3·4	Cr.		·43	Cr.	0		
4425·6	Ca.	Much strengthened on red side.					
6·2	Ti.		4426·20	Ti.	0	2	
4427·3	Ti.	Slightly strengthened.	4427·27	Ti.	2	8	
·5	Fe.		·48	Ti.	5		
			4428·71	V.-Cr.	1	2	Cannot detect strengthening in K.S.
4430·0	V.	Considerably strengthened.	29·96	V.	00	1–2	
·4	Fe.						
·8	Fe.						
4433·9	Fe.	Strengthened.	4433·95	Fe.	1	2	
4·2	Ti.		34·17	Ti.	0		

Kensington.			Mount Wilson.				
λ of Solar Lines.	Probable Origin. Un. = Unknown.	Behaviour in Arcturus Spectrum.	λ of Solar Lines.	Origin.	Intensity. Sun.	Intensity. Star.	Remarks. (K.S. = Kensington Spectrum.)
4435·1	Ca.	Slightly strengthened.	4435·13	Ca.	5	8	
·3	Fe.		·32	Fe.	2		
·9	Ca.						
4436·3	V.	Considerably strengthened.	4436·31	V.	0	3–4	
·5	Mn.		·52	Mn.	2		
4437·7	Un.	Very much strengthened.	4437·73		0	4	
·9	Un.		·86		00		
8·0	V.		8·01	V.	0		
			4441·88	V.	3	4–5	This individual line cannot be distinguished in bunch of lines in K.S.
			4443·98	Ti.	5	4–5	Cannot detect any change in K.S.
4444·4	Un.	Much strengthened.					
·6	V. Ti.						
·7	Fe. Ti.						
			4445·64	Fe.	1	2–3	Slightly strengthened in K.S.
			4452·17	V.	0	2	Strengthened in K.S.
4453·2	Mn.	Strengthened.					
·5	Ti.						
4456·0	Mn.	Slightly weakened.	4455·98	Mn.	2	6	
·1	Ca.		6·06	Ca.	3		
·5	Fe.						
·8	Ca.						
4457·6	Ti. V. Zr.	Slightly strengthened.					
·7	Mn.						
			4459·92	V.	1	3	Cannot detect any change in K.S.
			4460·39	V.	0	4	Certainly strengthened in K.S.
			·46	Mn.	1		
			·52		0		
4461·2	Mn.	Individually inseparable. Collectively considerably strengthened.					
·4	Fe.Zr.Ni.						
·5	Fe.						
·8	Fe.						
2·2	Fe. Mn.		4462·16	Fe.Mn.	3	4	
·5	V.						
·6	Ni.						
4463·6	Ti. Ni.	Strengthened.					
			4465·98	Ti.	1	1–2	Slightly strengthened in K.S.
4469·7	Co.	Strengthened.	4469·87	V.	00	*	*Blended with other lines on violet side.
9·9	V.						
4471·4	Ti.	Much strengthened.	4471·41	Ti.	0	1–2	
·8	Un.		·72		00	2–3	
			·85		0		
			·97		00		

Kensington.			Mount Wilson.				Remarks. (K.S. = Kensington Spectrum.)
λ of Solar Lines.	Probable Origin. Un. = Unknown	Behaviour in Arcturus Spectrum.	λ of Solar Lines.	Origin.	Intensity. Sun.	Intensity. Star.	
4475·0	Ti.	Much strengthened.	4475·03	Ti.	0	2	
4476·2	Fe.	Weakened.					
·3	Ag.						
4479·8	Fe.						
·9	Ti.	Strengthened.					
80·1	Un.						
·3	Fe.						
4481·3	? p Mg.						
·4	Ti.	Weakened.					
·5	Un.						
4482·3	Fe.						
·4	Fe.	Strengthened.					
·9	Ti. Fe.						
4491·7	Fe.	Slightly strengthened.					
4496·1	Un.		4496·12		1	4	
·3	Ti.	Much	·32	Ti.	1		
7·0	Cr.	strengthened.					
			4501·44	Ti.	5	4–5	Cannot detect change in K.S.
4501·9	Un.	Much					
2·4	Mn.	strengthened.					
4505·0	Fe.	Slightly strengthened.					
4507·0	Un.	Much strengthened.					Nearly evanescent in Sun. Distinct line in Arcturus.
4508·5	p Fe.	Weakened.	4508·46	Fe.	4	2–3	
4509·5	Un.	Strengthened.					
·6							
4512·9	Ti.	Slightly strengthened.	4512·91	Ti.	3	4	
4514·4	Fe. Co.						
·6	Un.	Slightly					
·7	Cr.	weakened.					
4518·2	Ti.		4518·20	Ti.	3	4	
·5	Un.	Much	4518·75	Ti.	0	2–3	
·9	Ti.	strengthened.	·87		0		
			4522·69	Fe. ?	0	7	
4522·8	p Fe.	Strengthened.	·80	p Fe.	3		
·9	Ti.		·97	Ti.	2		
4527·5	Ti.	,,	4527·49	Ti.	3	5	
			·63		0		
4530·9	Cr.						
1·1	Fe. ? Co.	Much					
1·3	Fe.	strengthened.					

Kensington.			Mount Wilson.				
λ of Solar Lines.	Probable Origin. Un. = Unknown.	Behaviour in Arcturus Spectrum.	λ of Solar Lines.	Origin.	Intensity. Star.	Intensity. Sun.	Remarks. (K.S. = Kensington Spectrum.)
			4533·42	Ti.	4	5	Inseparable from 4533·1 in K.S. Combined lines not strengthened.
			4534·95	Ti.	4	5	Cannot detect change in K.S.
4535·7	Ti.		4535·74	Ti.	3		
·9	Ti.		·88	Cr.	1	6	
·9	Zr.	Strengthened.	·91	Zr.	0		
6·1	Ti.		4536·09	Ti.	2	6	
·2	Ti.		·22	Ti.	2		
4540·7	Cr.	Considerably	4540·67	Cr.	2	*	* Not changed.
·9	Cr.	strengthened.					
4544·8	Cr.		4544·79	Cr.	1	5	
·9	Ti.		·86	Ti.	3		
5·3	Un.	,,					
·5	Cr. V.		4545·51	Cr. V.	0	1	
6·1	Fe. Cr.		6·13	Cr.	3	4	
4548·0	Fe.						
·9	Ti.		4548·94	Ti.	2	3–4	
			4549·64	Fe.	2	6	Cannot detect change in K.S.
			·81	Ti. Co.	6		
4552·6	Ti.	Strengthened.	4552·63	Ti.	2	4	
·7	Fe.		·72	Fe.	1		
			4555·66	Ti.	3	4	Cannot separate from surrounding solar lines in K.S.
			4456·06		3	5	Cannot detect any change in K.S. 4556·06 is p Fe. 4556·31 is Fe.
			·31		4		
			4558·83	Cr.?	3	1	Cannot detect change in K.S.
4560·1	Ni. Ti.	Considerably					
·3	Fe.	strengthened.					
			4562·81	Ti.	00	2	Strengthened in K.S.
			4563·94	Ti.	4	3	Cannot detect change in K.S.
			4569·69	Cr.	00	1–2	,, ,, ,,
			·79	Cr.	0		
4571·3	Mg.		4571·28	Mg.	5	7	
·9	Cr.	Collectively	·85	Cr.	1	1–2	
2·2	p Ti.	strengthened.	2·16	Ti.	6	4 5	
4574·4	Fe.	Strengthened.					
·9			4574·90	Fe.	2	3–4	
			5·08		00		
			4575·73	Zr.	00	1	Strengthened in K.S.
4576·53	p Fe.	Weakened.	4576·51	V.	2	1	
4577·4	V.	Strengthened.	4577·36	V.	0	3	

Kensington.			Mount Wilson.				Remarks. (K.S. = Kensington Spectrum.)
λ of Solar Lines.	Probable Origin. Un. = Unknown.	Behaviour in Arcturus Spectrum.	λ of Solar Lines.	Origin.	Intensity. Sun.	Intensity. Star.	
4578·7	Ca.	Slightly strengthened.	4578·73	Ca.	3	5	
			·91	V.	00		
4580·2	Cr.	Much strengthened.	4580·23	Cr.	3	4–5	
·6	V.		·59	V.	1	3	
·8	Fe. Ni.						
			4581·58	Ca.	4	10	Cannot detect any change in K.S.
			·69	Co. Fe.	4		
4584·02	p Fe.	Weakened.	4584·02	Fe.	4	3	
4586·0	Cr.	Considerably strengthened.	4586·05	Ca.	4	5–6	
·4	Cr.		·16		0		
·6	V.		·55	V.	1	3–4	
4587·3	Fe.	Weakened.					
4588·4	p Cr.	,,	4588·38		3	1	
4592·7	Ni.	Slightly weakened.					
·8	Fe.						
4594·3	V.	Considerably strengthened.	4594.30	V	2	4	
4600·9	Cr.	Strengthened.	4600·93	Cr.	3	6	
1·1	Un.		1·11		0		
1·2	Cr.		1·21	Cr.	0		
			4603·13	Fe.	6	7	Slightly strengthened in K.S.
4606·40	Ni.	,,	4606·40	Ni. C.	2	2–3	
4607·5	Sr.	Slightly weakened.	4607·51	Sr.	1	2	
·8	Fe.						
4609·5	Un.	Considerably strengthened.					
			4616·30	Cr.	4	5	Slightly strengthened in K.S.
4617·5	Ti.	Strengthened.	4617·45	Ti.	3	4	
4619·0	Fe.pCr.	,,					
·5	Fe.						
·7	Cr.		4619·71	Cr.	1	3–4	
			·96		00		
4620·7	Fe.	Weakened or lacking.	4620·69	Fe.	1	0	
			4622·06	Cr.	0	3	Cannot detect any change in K.S.
			·13	Cr.	1		
			4623·28	Ti.	2	3	,, ,,
4625·2	Fe.	Slightly weakened.					
			4626·36	Cr.	5	6	Slightly strengthened in K.S.
			4630·31	Fe.	4	5	,, ,,
4633·0	Fe.	Slightly strengthened.	4635·35	V.	00	1–2	Inseparable from {4635·5, ·8, 6·0} in K.S. Combined lines slightly stronger in star.

Kensington.			Mount Wilson.				
λ of Solar Lines.	Probable Origin. Un.= Unknown.	Behaviour in Arcturus Spectrum.	λ of Solar Lines.	Origin.	Intensity. Sun.	Intensity. Star.	Remarks. (K.S. = Kensington Spectrum.)
4636·0	Fe.	Slightly strengthened.					
4637·7	Fe.	Strengthened.					
·9	Cr.						
8·1	Ti.						
·2	Fe.						
4639·5	Ti.	Very much strengthened.	4639·54	Ti.	2	4–5	
·7	Cr.		·68	Cr.	0		
·8	Ti.		4639·85	Ti.	2	7	
40·1	Ti.		40·12	Ti.	1		
			4645·37	Ti.	0	2–3	Strengthened in K.S.
4646·3	Cr.	Considerably strengthened.	4646·35	Cr.	5	6	
4647·6	Fe.	Slightly weakened.					
4648·8	Ni.	Weakened.					
			4650·19	Ti.	0	1–2	Strengthened in K.S.
			4651·46	Cr.	4	5	Not strengthened in K.S.
			4652·34	Cr.	5	7	Cannot detect any change in K.S.
			4653·55		00	1	Slightly strengthened in K.S.
			·68		00		
4655·8	Un.	Collectively much strengthened.					
6·0	Ti.						
·2	Ti.		4656·23	Ti.	0	1–2	
·1	Cr.		·36	Cr.	0		
·6	Ti.		4656·64	Ti.	3	5	
7·2	Un.						
·4	pTi.		4657·38	Ti. ?	2	1	
·8	Un.						
4667·6	Fe.	Collectively strengthened.					
·8	Ti.						
·9	Ni.						
8·3	Fe.						
			4668·75		1	2	Cannot isolate from surrounding lines in K.S.
			4670·59		2	4	Strengthened in K.S.
4672·5	Un.	Weakened.					
3·3	Fe.						
4675·3	Ti.	Much strengthened.	4675·29	Ti.	1	2	
4678·3	Cd.	Weakened.					
9·0	Fe.						
9·4	Un.						
			4680·48		1	2	Cannot separate from 4680·3/·7 in K.S. Collectively strengthened.

Kensington.			Mount Wilson.				Remarks. (K.S. = Kensington Spectrum.)
λ of Solar Lines.	Probable Origin. Un. = Unknown.	Behaviour in Arcturus Spectrum.	λ of Solar Lines.	Origin.	Intensity. Sun.	Intensity. Star.	
4682·1	Ti.	Much strengthened.	4682·09	Ti.	3	5	
·3	Fe. ?						
·5	Co.						
·7	Fe. ?						
			4685·45	Ca.	1	2	
4687·6	Fe. ?	Considerably strengthened.	4687·85		00	2	
8·4	Fe.		·98	Zr.	0		
			4688·36	Fe.	2	2–3	Strengthened in K.S.
			·55		0		
			4690·98	Ti.	00	1	Inseparable from 4691·6 in K.S. Combined line winged on violet side.
4693·9	Ti.	Much strengthened.	4693·85	Ti.	0	2	
4·1	Ni. Cr.						
4698·6	Co.	Considerably strengthened.	4698·58	Co.	0	5	
·6	Cr.		·64	Cr.	1		
·8	Cr.		·80	Cr.	1		
·8	Cr.		·98	Ti.	1		
4703·2	Mg.	Weakened.					
4708·8	Un.	,,					
9·2	Ti.						
9·3	Fe.						
4709·9	Mn.	Strengthened.	4710·37	Ti.	00	5	
10·4	Ti.		·47	Fe.	3		
0·5	Fe.						
			4715·47	C. ?	00	2–3	Cannot detect any strengthening in K.S.
4715·9	Ni.	Considerably strengthened.					
			4717·76		0	2	Strengthened in K.S.
4722·8	Ti.	Very much strengthened.	4722·80		0	2–3	
3·3	Cr.		3·29	Cr.	00	4	
·4	Ti.		·36	Ti.	00		
4727·6	Fe.	Strengthened.					
·7	Mn.						
4729·9	Fe. ? Cr.	Slightly weakened.	4729·86	Fe. ? Cr.	1	1–2	
30·2	Un.						
			4733·78	Fe.	4	6	Slightly strengthened in K.S.
			4742·98	Ti.	1	2	,, ,, ,,
			4744·57	Fe. ?	3	2	Cannot detect any change in K.S.
4748·3	Fe. ?	Weakened.	4748·32	Fe. ?	4	2	
			4752·01	Na. ?	00	0	Cannot see this in K.S., either of Sun or star.
			4756·30	Cr.	2	3	Cannot detect any change in K.S.

Kensington.			Mount Wilson.				Remarks. (K.S. = Kensington Spectrum.)
λ of Solar Lines.	Probable Origin. Un. = Unknown.	Behaviour in Arcturus Spectrum.	λ of Solar Lines.	Origin.	Intensity. Sun.	Intensity. Star.	
4757·8 / 8·3 / 9·5	Fe. / Ti. / Ti.	Strengthened.	4758·31	Ti.	1	2	
4761·7	Mn.	Weakened.					
			4762·57	Mn.	5	7	Cannot detect any change in K.S.
4766·0 / ·6	Mn.	Strengthened.					
			4771·28	Ti. Co.	00	2	Cannot separate from strong solar line 4771·7 in K.S.
			4778·44	Ti.	00	0	Strengthened in K.S.
			4779·63	Fe.	1	2	Cannot separate from 4780·2 in K.S.
			4781·91		00	2–3	Strengthened in K.S.
			4789·53	Cr.	2	3	Cannot separate from 4789·8 in K.S. Combined lines strengthened.
4792·7 / 3·0	Ti. Cr. / Co.	"	4792·70	Ti. Cr.	2	3–4	
4796·3 / 7·1	Cr. Ti. / V.	"					
4799·6 / 800·0 / ·8 / 1·2	Fe. / Ti. / Ni. Fe. / Cr.	Collectively Strengthened.	4799·98	Ti.	1	2	
			4805·61	Ti.	0	2	Inseparable from 4805·2 in K.S. Combined lines slightly strengthened.
			4807·18	Ni.	2	1–2	Cannot detect any change in K.S.
4808·7 / ·9	Ti. / Fe.	Strengthened.					
4816·0	Un.	Considerably strengthened.					
			4820·59	Ti.	1	3	Cannot separate in K.S. Combined lines slightly strengthened.
			4821·31		0	00	
			4823·70	Mn.	5	6	Cannot separate from 4824·3 in K.S. Combined lines not strengthened.
			4825·53 / ·67	Ti.	00 / 000	1	Considerably strengthened in K.S.
4827·6 / ·8	V. / Ti.	Much strengthened.	4827·64 / ·80	V. / Ti.	000 / 00	2–3	

Kensington.			Mount Wilson.				Remarks. (K.S. = Kensington Spectrum.)
λ of Solar Lines.	Probable Origin. Un. = Unknown.	Behaviour in Arcturus Spectrum.	λ of Solar Lines.	Origin.	Intensity. Sun.	Intensity. Star.	
4829·2 ·6	Ni. Cr.	Weakened.	4829·55	Cr.	2	3	
4831·4	Ni.		4831·36	Ni.	3	2	
·8	V.		4831·83		00	3	
2·6	V.	Very much strengthened, apparently most in the centre.	4832·62	Mn.	00	3	
·9	Fe.		4832·90	Fe.	3	2	
			4836·42		0	00	Cannot detect any change in K.S.
			4841·07	Ti.	3	4	Inseparable from 4840·5. Combined lines not strengthened.
			4847·50	Ca.	0	1–2	Slightly strengthened in K.S.
			4848·44		2	3	Cannot separate in K.S. Collectively strengthened.
			·60	Ti	0000		
			4849·08	Fe.	1	1–2	
4851·7	Ca. V.	Much strengthened.	4851·69	Ca. V.	1	4–5	
4855·6	Ni.						
·9	Fe.	Strengthened.					
6·2	Ti.		4856·20	Ti.	1	3	
4861·5	Hβ	Weakened.	4861·53	H.	30	25	
4864·9	V.	Considerably strengthened.	4864·92	V.	1	3	
4868·1	Co.						
·5	Ti.	,,	4868·45	Ti.	0	3	
			·60		00		
			4870·32	Ti.	1	2	Slightly strengthened in K.S.
4875·7	V.						
6·1	Fe.	,,	4875·67	V.	1	3	
			4876·59		1	0	Cannot detect any change in K.S.
			4881·74	V.	1	5	Combined with 4882·3, considerably strengthened in K.S.
			·90	Fe.	2		
			4885·26	Ti.	2	3	Combined with 4885·5, considerably strengthened in K.S.
			4888·71	Cr.	00	3–4	
4888·8	Fe.		·82	Fe.	2		
9·2	Fe?	Slightly strengthened.					
·3	Fe.						
			4893·03	Fe.	1	0	Cannot detect any change in K.S.
4900·1	Ti. La.	Considerably strengthened.	4900·10	Ti. La.	2	4	
·3	Y. ?						

The foregoing comparisons tend to show that the Arcturian spectrum represents a lower stage in the temperature sequence than the solar spectrum. On the whole, the arc lines of the metals are, if anything, slightly stronger in the Arcturian spectrum; and in cases where it is possible to isolate the enhanced lines of the metals—which are mainly weak in the Sun—it is found that they are generally weaker still in Arcturus.

This is, of course, in accordance with the general condition that in passing from the lower stages, such as the Piscian (19 Piscium) and Arcturian (Arcturus) to the higher, such as the Procyonian (Procyon) and Sirian (Sirius), the arc lines of the metals gradually weaken, whilst the enhanced lines strengthen.

A comparison of the relative intensity of the strong iron line λ 4326 near Hγ, and the Hγ line itself in the two spectra, clearly indicates also that Arcturus represents the lower temperature condition. In Arcturus the 4326 line is distinctly stronger than Hγ, while in the Sun Hγ is the stronger line. This is also in agreement with the weakening of the iron lines and the strengthening of the hydrogen lines in going up the stellar temperature scale.

There are other very striking variations in the lines of the two spectra which tend to throw some light on the spectra of sun-spots. This discussion is, however, better reserved for a separate chapter.

PHYSICAL RELATIONSHIP OF THE VAPOURS IN SUN-SPOTS, SOLAR PHOTOSPHERE, AND THE ABSORBING ATMOSPHERE OF ARCTURUS.

One of the most marked features revealed by a comparison of the solar and Arcturian spectra is the increased intensity in the latter of many of the solar-vanadium and solar-titanium lines. In the majority of cases where there is a great increase in the intensity of corresponding lines, or groups of lines, in passing from the solar to the stellar spectrum, either vanadium or titanium is involved. Of the two metals vanadium is, in this respect, the more strongly affected.

It was pointed out in a previous paper* that in the observations of sun-spot spectra at Kensington since 1892 the elements whose lines are most prominently widened in the region investigated are vanadium and titanium. The vanadium lines, though fewer in number, are apparently more strongly affected than the titanium lines. This predominance in sun-spot spectra of the widened vanadium and titanium lines, and the strengthening of lines of the same elements in the transition from the solar spectrum to that of Arcturus, suggests that the temperature conditions of the absorbing vapours in the spot nuclei are about the same as the mean temperature conditions of the absorbing vapours in Arcturus. It may be as well to state here that owing to the fact that the comparison of the solar and

* Roy. Soc. Proc., vol. 74, p. 53, 1904.

stellar spectra could only be made in the part of the spectrum between 3990 and 4990—whereas the sun-spot observations have been confined to the visual region F to D—no comparison could be made between the intrinsic vanadium lines affected. As the lines of vanadium in the two regions mentioned, however, appear to be of similar behaviour in laboratory spectra, it is a fair assumption to make that they are subject to similar conditions of temperature in the two celestial light-sources.

The close connection of the lines strongly affected in sun-spots and those affected in Arcturus has, moreover, been definitely established by the investigations of Hale and Adams, who show by a direct comparison of the Arcturian and sun-spot spectra that the two sets of lines are almost identical.

As the mean temperature of the absorbing vapours in Arcturus has, from other considerations, been shown to be lower than that of the Sun, a lower temperature than the latter is also indicated for the spot vapours generally.

With regard to the physical condition of such stars as Arcturus and those belonging to the still lower third and fourth types, Hale and his co-workers held* that the collective evidence as to the lines strengthened in sun-spots being much intensified in those types of spectra suggests that spots like those on the Sun may form a characteristic feature of such stars, and that there is a greater preponderance of spots in these stars than in the Sun.

In a more recently published Kensington paper,† the results embodied in which were obtained before the receipt of Hale's publication, it was stated :— "From the evidence adduced it seems a far more probable explanation to suppose " that these lines are intensified in sun-spots and strengthened in those stars " which have been placed on lower temperature levels than the Sun, because " the general temperature conditions are similar ; that is to say, the fall of " temperature experienced by the metallic vapours in passing from the photo- " sphere to the spot nucleus is of the same order as that to which an absorbing " atmosphere is subjected in passing from the temperature conditions of Capella " or the Sun to that of Arcturus or the lower temperature stars.

In a subsequent paper by Hale, Adams and Gale, "On the Cause of the " Characteristic Phenomena of Sun-Spot Spectra,"‡ the following statements occur which support the view taken in the Kensington paper previously mentioned :—

Page 203. "The simplest way of accounting for the characteristic phenomena of spot-spectra seems to be the hypothesis that the metallic vapours in the spot are cooler than the corresponding vapours in the reversing layer."

Page 205. "The behaviour of stars of the lines affected in sun-spots appears to be consistent with the view that temperature changes alone are sufficient to account for their variation in intensity."

Page 205 (footnote). "Formerly we were inclined to the view that the presence of spot lines in the spectra of red stars indicated the presence of spots like those on the Sun. Our recent work has led us to the opinion that the

* Decennial Publications of the University of Chicago, vol. 8, p. 379.

† Roy. Soc. Proc., vol. 74, p. 53, 1904. ‡ Ast. Phys. Jour., vol. 24, p. 185, 1906.

comparatively low temperature of these stars offers the simplest explanation of the observations."

It follows from this that the view stated in the Kensington paper of 1904 is now accepted.

COMPARISON OF SOLAR SPECTRUM AND SPECTRA OF SECCHI'S THIRD TYPE.

The foregoing conclusion suggested further enquiry as to which lines are affected in passing to stellar spectra of Secchi's third and fourth types (Antarian and Piscian groups respectively in the Kensington classification) with the object of possibly throwing further light on the relative positions of these types, and others already investigated, on the temperature scale. Unfortunately no photographs exist at Kensington of stars of Secchi's third type of sufficient dispersion to make a satisfactory comparison with the solar spectrum. Pickering, however, gives a comparison list* of the lines in α Orionis and other stars with the solar lines. A table has been prepared showing Pickering's solar lines which are intensified in the spectrum of α Orionis. The region investigated is from λ 3980 to F (4861·7). The probable origins of the lines, as derived from Rowland's tables of solar wave-lengths, are also given in the table.

Many of the stellar lines are undoubtedly of compound origin, and, owing to small dispersion, probably consist of close groups of lines which can be separated on a large-scale solar map.

An analysis of the origins probably involved in these lines or groups shows that, of 79 lines, 48 include iron, 25 titanium, 13 chromium, and 9 vanadium.

LINES STRENGTHENED IN PASSING FROM SOLAR SPECTRUM TO THAT OF α ORIONIS.

Taken from Pickering's Tables.†

Wave-Length (Harvard).	Intensity (Harvard).		Probable Origin (Kensington). Un. = Unknown.	Remarks.	Wave-Length (Harvard).	Intensity (Harvard).		Probable Origin (Kensington). Un. = Unknown.	Remarks.
	Sun.	α Orionis.				Sun.	α Orionis.		
3982·0	2	4	Ti. Fe.		4030·8	4	8	Fe. Mn. Ti.	
3990·0	3	4	Ti. Fe.		4034·6	4	5	Mn. Fe.	
3998·8	2	4	Ti.		4041·5	3	5	Fe. Mn.	

* Annals Harv. Coll. Obs. vol. 28, Pt. I., p. 58.

† Annals Harv. Coll. Obs., vol. 28, Pt. I., p. 58 *et seq.*

Wave-Length (Harvard).	Intensity (Harvard).		Probable Origin (Kensington). Un. = Unknown.	Remarks.
	Sun.	α Orionis.		
4045·9	5	7	Fe.	
4055·0	3	6	Fe. Ti.	
4063·7	5	10	Fe.	
4071·9	4	8	Fe.	
4077·9	4	5	Sr.	
4086·8	2	3	? La.	
4090·2	2	3	Fe. Mn.	
4096·2	3	4	Fe.	
4105·3	2	3	V.	
4113·1	2	4	Fe.	
4123·9	2	3	Fe. Ti. V.	
4129·8	2	3	Un.	
4140·3	2	3	Fe. Un.	
4143·9	4	8	Fe.	
4165·6	2	3	Fe. Ce. ?	
4169·8	1	2	Un.	
4172·9	3	12	Fe. Un.	
4175·1	2	3	Fe.	
4187·6	4	5	Fe.	
4191·8	3	6	Fe.	
4206·9	2	3	Fe.	
4215·7	3	9	Fe. Sr.	
4223·7	2	3	Un.	
4227·0	5	40	Ca.	
4233·6	4	6	Fe.	
4247·3	3	4	Fe.	
4254·5	4	5	Cr.	
4271·7	5	8	Fe.	
4275·0	4	6	Cr. Ti.	
4289·9	3	6	Cr. Ti.	
4291·2	3	7	Ti. Fe.	
4292·2	2		Cr. V.	
4299·2	3	8	Ca. Ti. Fe.	
4300·8	3			
4305·8	3	4	Fe. Sr. Ti. Cr.	
4309·5	3	4	Fe.	
4314·3	2	7	Sc. Ti. Fe.	
4315·2	4			
4226·0	5	11	Fe.	
4330·9	2	3	Ti. Ni.	
4337·6	3	7	Cr. Fe.	
4344·7	2	3	Cr. Ti.	
4348·0	2	4	Fe.	
4352·0	4	5	Mg. Cr.	
4376·1	3	6	Fe.	
4383·7	5	13	Fe. V.	
4385·2	3			
4395·3	3	4	Ti. V.	
4401·6	3	4	Fe. Ni.	
4405·0	5	7	Fe.	
4408·5	3	7	V. Fe.	
4422·8	2	3	Fe.	
4427·4	3	4	Fe. Ti.	
4430·8	2	3	Fe.	
4435·2	3	8	Ca. Fe.	
4462·0	3	5	Fe. Mn. V.	
4473·0	2	3	Fe. Mn.	
4482·5	4	5	Fe.	
4490·0	2	5	Fe. Mn.	
4497·0	2	4	Cr.	
4507·0	0	2	Un.	
4518·0	2	3	Ti.	
4535·0	2	7	Ti. Cr.	
4536·0	3			

Wave-Length (Harvard)	Intensity (Harvard). Sun.	Intensity (Harvard). α Orionis.	Probable Origin (Kensington). Un. = Unknown.	Remarks.
4541·6	2	3	Cr.	
4561·0	1	2	Un.	
4572·2	3	1	Ti.	
4580·2	2	3	Cr. V.	
4595·9	2	3	Ni. Fe. Cr.	
4640·0	2	3	Ti.	
4647·6	2	1	Fe.	
4657·0	2	4	Ti.	
4668·0	4	5	Ti. Fe. Ni.	
4710·2	2	3	Fe. Ti. Mn.	
4743·0	1	2	Ti.	
4766·1	3	4	Mn.	
4799·9	2	3	Ti.	
4832·9	2	4	V. Fe.	

Recourse was also had to a reproduction in a paper by Professor Hale,* showing a comparison of the solar spectrum with that of μ Geminorum, a star of Secchi's third type, and belonging to the Antarian group in the Kensington classification. The solar lines or groups of lines which appear to be intensified in the third-type spectrum were noted for the purpose of analysing the origins of the lines involved in these identifications, and to ascertain the relation of the metals involved to those whose lines had previously been found to be affected in the spectum of Arcturus. As Professor Hale's photographic comparison referred to a different region of the spectrum (5100 to 5800) from that which had been studied in the Solar-Arcturus comparison (3989 to 4889), it was of course impossible to compare the lines actually affected in the two cases. Immediately after the foregoing comparison had been made, the volume embodying Hale, Ellerman, and Parkhurst's work on the spectra of stars of Secchi's fourth type† was received at Kensington. As this contained a reproduction showing a comparison of the solar spectrum with the spectra of types III. and IV. in the region λ 4330 to λ 4900, it was possible to extend the enquiry with regard to the lines strengthened in third-type spectra into that region. This has been done, and the detailed results of the comparison are given in the following table. It may be pointed out that Hale's reproductions of the stellar spectra, though most admirable, do not allow the separation of the groups of solar lines into their individual components, except in very few cases. The lines included in brackets in the table represent, so far as it is possible to judge, the groups of solar lines to which the stellar lines appear to correspond. The remarks with regard to change of intensity have been confined to general terms, such as "slightly stronger," "considerably stronger," "much stronger," as it was thought to be better, owing to the probable compound nature of many of the stellar lines, than giving comparative numerical intensities.

* Astrophysical Journal, vol. 9, p. 273, 1899.

† Decennial Publications of the Chicago University, from vol. 8, 1903.

LINES STRENGTHENED IN PASSING FROM THE SOLAR SPECTRUM TO SECCHI'S THIRD TYPE.

(Deduced from the reproductions published by Prof. Hale. Ast. Phys. Jour., vol. 9, p. 273, and Decennial Publications of the Chicago University, vol. 8, Plate 10.)

Rowland's Solar Lines.		Remarks on Intensity in Third-type Spectrum.
λ	Origin.	
4412·3	V. Cr.	Stronger than in Sun.
4412·4		
4436·3	V.	Considerably stronger than in Sun.
4436·5	Mn.	
4437·1	Fe. Ni.	
4438·0	V.	Slightly stronger than in Sun.
4438·5	Fe.	
4441·9	V.	Much stronger than in Sun.
4444·6	V. Ti.	" " "
4444·7	Fe.-Ti.	
4450·1	Un.	" " "
4453·5	Ti.	Stronger than in Sun.
4453·9	Ti.	
4459·9	V.	Considerably stronger than in Sun.
4460·4	V.	
4460·5	Mn.	
4471·0	Ti.	" " "
4471·4	Ti.	
4475·0	Ti.	Stronger than in Sun.
4482·3	Fe.	" "
4482·4	Fe.	
4482·9	Ti.-Fe.	
4489·9	Fe.	Much stronger than in Sun.
4490·3	Mn.-Fe.	
4496·1	Un.	" " "
4496·3	Ti.	
4497·0	Cr.	
4512·9	Ti.	" " "
4535·0	Ti.	Considerably stronger than in Sun.
4535·7	Ti.	
4536·1	Ti.	
4536·2	Ti.	
4540·7	Cr.	Stronger than in Sun.
4540·9	Cr.	
4541·2	Cr.	
4541·7	Cr.	

Rowland's Solar Lines.		Remarks on Intensity in Third-type Spectrum.
λ	Origin.	
4554·2	Ba.	Considerably stronger than in Sun.
4560·1	Ti.-Ni.	Stronger than in Sun.
4560·3	Fe.	
4563·6	Ti.	Considerably stronger than in Sun.
4574·4	Fe.	Slightly stronger than in Sun.
4574·9	Fe.	
4580·2	Cr.	Considerably stronger than in Sun.
4580·6	V.	
4580·8	Fe.-Ni.	
4591·0	Un.	Much stronger than in Sun.
4594·3	V.	Very much stronger than in Sun.
4606·4	Ni.-C.	Probably head of carbon band.
4626·4	Cr.	Stronger than in Sun.
4629·5	Ti.-Co.	Considerably stronger than in Sun.
4639·5	Ti.	Much stronger than in Sun.
4639·7	Cr.	
4639·8	Ti.	
4640·1	Ti.	
4640·5	Un.	
4646·3	Cr.	Very much stronger than in Sun.
4652·3	Cr.	Slightly stronger than in Sun.
4675·3	Ti.	Considerably stronger than in Sun.
4682·0	Ti.	Much stronger than in Sun.
4682·3	Fe. ?	
4682·5	Co.	
4682·7	Fe.	
4687·6	Fe.	Considerably stronger than in Sun.
4688·4	Fe.	

Rowland's Solar Lines. λ	Origin.	Remarks on Intensity in Third-type Spectrum.
4698·6	Co.	Slightly stronger than in Sun.
4698·6	Cr.	
4698·8	Cr.	
4698·9	Ti.	
4722·3	Zn.	,, ,, ,,
4732·6	Ni.	,, ,, ,,
4758·3	Ti.	Considerably stronger than in Sun.
4759·5	Ti.	
4831·8	V.	,, ,, ,,
4832·6	V.	
4832·9	Ti.	
		Owing partly to the line absorption being somewhat masked by the bands in the third-type spectrum, and partly to a break (4980-5100) in Hale's two reproductions, no strengthened lines are given in this table for the region between F and the *b* group.
5204·7	Cr.	Much stronger than in Sun.
5204·8	Fe.	
5205·9	V.	
5206·2	Cr. Ti.	
5208·6	Cr.	,,
5208·8	Fe.	
5210·6	Ti.	
5240·0	Sc.	Stronger and broader than in Sun.
5247·2	Fe.	Much stronger than in Sun. Stellar line seems to lie to the more refrangible side of the solar group.
5247·5	Ti.	
5247·7	Cr.	
5250·4	Fe.	Stronger than in Sun.
5250·8	Fe.	
5269·7	Fe.	Much stronger than in Sun.
5270·4	Ca.	
5270·6	Fe.	
5288·7	Fe.	Very weak in Sun. Moderately strong in star.
5328·2	Fe.	Much stronger than in Sun.
5328·5	Cr.	
5328·7	Fe.	
5329·3	Cr.	
5330·2	Fe.	
5397·3	Fe.	Considerably stronger than in Sun. Stellar line perhaps more refrangible than solar line.
5446·8	Ti.	Stronger than in Sun. ? beginning of an absorption band.
5447·1	Fe.	
5455·7	Fe.	Much stronger than in Sun.
5455·8	Fe.	
5506·1	Mn.	,, ,,
5507·0	Fe.	
5512·5	Fe.	Considerably stronger than in Sun.
5512·7	Ti.	
5513·2	Ca.	
5597·0	—	Lacking in Sun. Well marked in star. ? head of absorption band.
5632·0	—	Lacking in Sun. Probably head of citron carbon band.

An analysis of the origins of the lines in the foregoing table shows that the chief metals involved are iron, titanium, chromium, and vanadium. The majority of the lines which are considerably intensified in the third-type spectrum involve either titanium or vanadium. The lines of vanadium, although fewer than those of titanium, are probably more affected with regard to degree of intensification. In this way there is very little difference between the line absorption of the third-type stars and that of Arcturus, that is to say, the solar lines shown to be strengthened in either the Arcturian spectrum or spectra of the third type chiefly belong to the same metals, vanadium, titanium, chromium, and iron. From the point of view of the behaviour of the metallic lines, then, the step from the temperature conditions of the Sun's vapours generally to those of Arcturus seems to be far greater than that from the Arcturian conditions to those of Secchi's third-type stars.

RELATION OF FOURTH-TYPE STARS TO THOSE OF THE THIRD TYPE AND ARCTURUS.

No "fourth-type" stars being available for investigation at Kensington it was impossible to institute a similar comparison as has been done between Arcturus and the solar spectra. Professor Hale and his colleagues have, however, in their analysis of the spectra of fourth-type stars* found that so far as the line absorption is concerned there is very little difference between the spectra of the third and fourth types. They also showed that the prevalence and greatly increased strength of lines of vanadium and titanium in these spectra suggests a similarity of conditions for their absorbing vapours as those existing in sun-spots. It would appear, then, that from the evidence afforded by the analysis of stellar spectra of the Arcturian and Secchi's third and fourth types, it is fairly well established that there is a general similarity in the line absorption of these stars and that of sun-spots, with the sun-spot lines perhaps further developed in the lower types.

RELATION OF THE CHROMOSPHERIC SPECTRUM TO THOSE OF THE SUN (FRAUNHOFERIC), SUN-SPOTS, AND LOWER-TYPE STARS.

It has previously been shown† that the spectrum of the chromosphere, in so far as the metallic lines are concerned, strongly resembles that of the Polarian (*e.g.* γ Cygni) and Procyonian (Procyon) types. These latter represent corresponding heights on the temperature curve, the Polarian being on the ascending side and Procyonian on the descending side. The enhanced lines of such metals as iron and titanium, somewhat weakly represented in the Fraunhoferic spectrum, have developed considerably in the chromospheric spectrum, whereas the strong solar-arc lines are in general weaker in that spectrum.

It has been shown by Fowler‡ that many of the enhanced lines are weakened in sun-spot spectra. Adams had also shown that these lines are weakened in passing from the solar spectrum to that of Arcturus. This behaviour of the enhanced lines is, then, the converse of what happens in the chromosphere. We thus get from a consideration of the enhanced lines a sequence of changes thus:—

Chromosphere (= Procyon): Enhanced lines strong.
Solar Spectrum (= Fraunhoferic): Enhanced lines present but weak.
Sun-Spots (= Arcturus): Enhanced lines still weaker than in Sun.

* Decennial Publications of Chicago University, vol. 8, p. 133.
† Phil. Trans., vol. 201, pp. 205–222.
‡ Monthly Notices, R.A.S., vol. 66, p. 361.
§ Ast. Phys. Jour., vol. 24, p. 69, 1906.

Owing to the lack of definition and separation of the lines in the Kensington eclipse spectra, as compared with the Arcturian and solar spectra photographed on the same scale, it has been found impossible to make a satisfactory direct comparison of the stellar and chromospheric spectra for the purpose of showing how the lines strengthened in Arcturus are affected in the chromosphere. In the light of the converse behaviour of the enhanced lines in the Arcturian and chromospheric spectra it is most probable that the lines strengthened in Arcturus are weakened in the chromosphere. To establish this point satisfactorily a chromospheric spectrum taken with a slit, and having larger dispersion than those hitherto obtained, will be necessary. Whatever dispersion is employed, however, it will be necessary to have the stellar and solar photographs on the same scale, as the direct comparison of the spectra is far better, in an enquiry of this kind, than a comparison of lists of lines reduced from the various spectra.

II.

THE SPECTRUM OF ε URSÆ MAJORIS.

INTRODUCTION.

In a previous Kensington publication, "Some Stars with Peculiar Spectra,"* ε Ursæ Majoris was one of the stars discussed. It was pointed out that, although its spectrum approached more nearly to the Sirian spectrum than to that of any other type-star in the Kensington classification, there were indications that its real position is between the Sirian and Procyonian types. Some of the general results of a comparison of the spectrum under discussion with that of Sirius were given, chief of which were the weakening of the silicium (Group II.) lines and the strengthening of the proto-chromium lines. A detailed discussion was reserved for a future paper.

Since the time of publication of the paper mentioned much better photographs, with increased dispersion, have been obtained of the ε Ursæ Majoris spectrum, and comparison with other standard stellar spectra has enabled us to make a considerably more detailed investigation, the results of which are given in the present paper.

A reduction of the lines in the spectrum from λ 3898 to Hβ (4861·5) has been made by direct comparison with the spectra of α Cygni, Sirius, Procyon and the Sun, all photographed on the same scale. The wave-lengths of the lines in the three stars named have been previously published.† For the solar wave-lengths Rowland's tables have been used. The wave-lengths, intensities, and probable origins of the lines are given in the following table. No comparison columns could be given containing other spectroscopists' results, as no detailed record of the lines in this spectrum has previously been published.

Where in the "λ of Probable Origin" column a wave-length is given after "Un." in the previous column, the wave-length is that of the "solar" line of unknown origin to which the stellar line is thought to correspond.

WAVE-LENGTHS, INTENSITIES, AND PROBABLE ORIGINS OF LINES IN THE SPECTRUM OF ε URSÆ MAJORIS.

ε Ursæ Majoris. (Kensington.)		Probable Origin. Un. = Unknown.	λ of Probable Origin.	Remarks.
λ	Int. Max. 10.			
3898·2	2	V. Fe.	3898·15 3898·23	
3900·7	3	p Ti.	3900·68	
3903·3	2	? p V.	3903·40	

* Roy. Soc. Proc., vol. 77, page 550.

† "Catalogue of 470 of the Brighter Stars." (Published by the Solar Physics Committee.)

"On the General Spectra of certain Type-Stars and the Spectra of several of the Brighter Stars in the Green Region." (Published by the Solar Physics Committee.)

ε Ursæ Majoris. (Kensington.) λ	Int. Max. 10.	Probable Origin. Un. = Unknown.	λ of Probable Origin.	Remarks.
3904·0	1	Fe.	3904·05	
3905·7	3	p Cr. Si.	3905·66 3905·66	
3908·1	2	Fe.	3908·08	
3911·4	3	Un.		
3913·6	2–3	p Ti.	3913·61	
3914·5	1–2	? p V.	3914·44	
3918·8	3–4	? Fe.	3918·79	
3926·0	3	? Fe.	3926·09	
3928·2	2	? Fe.	3928·08	
3930·3	2	? Fe.	3930·45	
3933·8	6	p Ca.	3933·83	
3936·0	3–4	p Fe.	3935·92	
3938·6	3	Un.	3938·44 3938·55	
3944·1	1	Al.	3944·16	
3945·2	2–3	Fe.	3945·03 3945·26	
3955·5	2	Fe.	3955·48	
3956·6	3	Co. Ti. Fe. Fe.	3956·48 3956·60 3956·82	
3960·4	1–2	Fe.	3960·42	
3961·6	1	Al.	3961·67	
3968·6	10	p Ca.	3968·63	
3970·2	10	H.	3970·18	Hε.
3976·8	2	Fe. Cr. Fe.	3976·53 3976·69 3976·77 3976·84 3977·01	
3978·9	1	? Cr.	3978·81	
3979·7	2–3	p Cr.	3979·66	
3982·0	2–3	Ti. ? Fe.	3981·92 3982·14	
3984·0	3	Cr. Fe.	3984·06 3984·11	

ε Ursæ Majoris. (Kensington.)		Probable Origin. Un. = Unknown.	λ of Probable Origin.	Remarks.
λ	Int. Max. 10.			
3986·3	2	Fe.	3986·32	
3987·0	1	Un. Mn.	3986·90 3986·98	
3989·9	1	Ti.	3989·91	
3990·5	2	Fe.	3990·53	
3994·3	1	Fe.	3994·26	
3997·6	1–2	Fe. Un.	3997·55 3997·64	
4002·7	2	p Fe.	4002·77	
4003·6	1–2	p Cr.	4003·55	
4005·5	3–4	Fe.	4005·41	
4006·8	1	Fe. Un.	4006·78 4006·90	
4012·6	5	p Ti. p Cr.	4012·54 4012·63	
4015·7	1	p Ni.	4015·76	
4017·2	2	Un. Fe.	4017·24 4017·31	
4018·3	3	Mn. Fe.	4018·25 4018·42	
4022·0	2	Fe.	4022·02	
4024·8	2	Ti. Fe.	4024·71 4024·86	
4025·2	1–2	p Ti.	4025·29	
4028·5	1–2	p Ti.	4028·50	
4030·9	5	Mn.	4030·87	Abnormally strong in this spectrum.
4032·0	1	Fe.	4032·06	
4033·2	4–5	Mn.	4033·22	Abnormally strong in this spectrum.
4034·6	1	Mn.	4034·64	
4035·9	1–2	Mn.	4035·88	
4038·1	2–3	p Cr.	4038·10	
4038·9	1	Fe. Un.	4038·77 4038·94	
4041·5	2	Fe. Mn.	4041·43 4041·53	
4044·0	2–3	Fe. Un.	4044·06 4044·14	

ε Ursæ Majoris. (Kensington.) λ	Int. Max. 10.	Probable Origin. Un. = Unknown.	λ of Probable Origin.	Remarks.
4044·7	1–2	Un. Fe.	4044·64 4044·77	
4046·0	4–5	Fe.	4045·98	
4048·8	3	p Fe. Mn.	4048·93	
4052·1	3	p Cr.	4052·10	
4053·9	3	p V. p Ti.	4053·80 4053·98	
4057·6	2	Fe. Un.	4057·50 4057·67	
4058·9	1-2	p Cr.	4058·92	
4063·8	4	Fe.	4063·76	
4064·6	1	Fe.	4064·61	
4067·2	2–3	Fe. p Ni. Fe.	4067·14 4067·30 4067·43	
4068·1	2	Fe. Mn.	4068·14	
4070·0	1–2	Un.		
4071·0	1–2	Fe. p Cr.	4070·93 4071·07	
4071·9	1–2	Fe.	4071·91	
4072·7	1–2	Fe.	4072·65	
4074·9	1	Un. Fe.	4074·84 4074·95	
4077·1	2–3	Un. Cr.	4077·03 4077·22	
4077·9	3-4	p Sr.	4077·88	
4082·5	2–3	p Cr.	4082·50	
4083·8	2	Mn.	4083·78	
4085·2	1	Fe.	4085·16	
4086·3	2	Un. Co.	4086·13 4086·47	
4087·8	2–3	Un.		
4089·0	2	Fe.	4088·71 4089·37	
4096·2	2	Fe.	4096·13 4096·26	
4098·6	2–3	Fe. Ca.	4098·34 4098·69	

ε Ursæ Majoris. (Kensington.) λ	Int. Max. 10.	Probable Origin. Un. = Unknown.	λ of Probable Origin.	Remarks.
4101·8	10	H.	4101·85	Hδ.
4107·7	1–2	Fe.	4107·65	
4111·2	3	p Cr.	4111·25	
4113·0	3	Fe.	4113·12	
4118·9	2	Fe. Co. Fe.	4118·71 4118·93 4119·05	
4120·4	1–2	Fe.	4120·37	
4122·8	3	Un.	4122·82	This line of unknown origin is also well marked in α Cygni and Sirius, and is almost certainly the equivalent of the unknown solar line 4122·82.
4124·7	1–2	Un.		
4128·2	1–2	p Si. (II.)	4128·20	Very much weaker than in Sirius.
4128·9	3	Un.	4128·89	This line seems to be special to ε Ursæ Majoris. It forms a companion line to Si. 4128·2, which is weak in this star. The line is probably the counterpart of the solar unknown line 4128·89.
4131·1	1-2	p Si. (II.)	4131·04	Very much weaker than in Sirius.
4132·6	5	Un.	4132·69	Quite an outstanding line in this star. The same line occurs in Procyon, but not so prominently. Sirius also has a weak line here. Possibly the line is the equivalent of the solar unknown line 4132·69.
4134·6	1–2	Fe.	4134·49 4134·59 4134·84	
4137·2	2–3	Fe.	4137·16	
4142·4	1	Cr. Un.	4142·33 4142·47	
4143·8	3-4	Fe. Un. Fe.	4143·57 4143·66 4144·04	
4145·9	3–4	p Cr.	4145·91	
4147·7	1–2	Fe.	4147·84	
4152·2	1	Fe.	4152·11 4152·34	
4154·4	3–4	Fe.	4154·07 4154·67 4154·98	Broad line coinciding with group of solar lines.
4156·7	2–3	Un. Fe.	4156·47 4156·97	
4157·9	1	Fe.	4157·95	

ε Ursæ Majoris. (Kensington.) λ	Int. Max. 10.	Probable Origin. Un. = Unknown.	λ of Probable Origin.	Remarks.
4159·1	2	Fe. Un.	4158·96 4159·35	
4161·7	3	p Ti.	4161·70	Broad and hazy, probably compound line.
4163·8	2	p Ti.	4163·82	
4165·6	1	Fe.	4165·55	
4167·4	< 1	Un.	4167·44	
4171·1	3–4	? Fe. Ti.	4171·07 4171·23	Abnormally strong in this star.
4172·2	4	p Ti. Fe.	4172·07 4172·30	Abnormally strong in this star.
4173·6	2–3	p Fe. p Ti.	4173·62 4173·70	
4175·8	1	Fe.	4175·81	
4177·7	1–2	? p Y.	4177·75	
4179·0	4	p Fe.	4179·05	
4182·0	3	Fe. Un.	4181·92 4182·14	
4184·2 to 4185·1	2–3	Un. Un. Fe. Cr.	4184·16 4184·47 4185·06	Broad line, probably double or multiple.
4187·2 to 4188·0	2–3	Fe. Fe. p Ni. Fe. Un.	4187·20 4187·75 4187·8 4187·94 4188·02	Broad line, probably multiple.
4188·9	1–2	Un.	4188·89	
4190·3	1	? Cr.	4190·29	
4191·7	3	Fe.	4191·60 4191·84	
4195·6	3–4	Fe.	4195·49 4195·79	
4196·4	2	Fe.	4196·37	
4198·4 to 4199·3	3	Un. Fe. Fe. Fe.	4198·40 4198·49 4198·80 4199·27	Broad line, probably multiple.
4201·1	1	Fe.	4201·09	
4202·2	2	Fe.	4202·20	
4204·1	1–2	Fe. ? La.	4204·10 4204·16	

ε Ursæ Majoris. (Kensington.)		Probable Origin. Un. = Unknown.	λ of Probable Origin.	Remarks.
λ	Int. Max. 10.			
4205·2	2	Un.	4205·19 4205·24	
4209·0	1	? Zr.	4209·14	
4210·5	1–2	Fe. Un.	4210·49 4210·56	
4213·8	1–2	Fe.	4213·81	
4215·7	3–4	p Sr.	4215·70	
4217·7	2–3	Fe. Cr.	4217·72	
4219·5	3	Fe. Un.	4219·52 4219·58	
4420·5	< 1	Fe.	4220·51	
4222·4	3	Fe.	4222·38	
4224·7 to 4225·6	2	Cr. Fe. p Cr. Fe.	4224·67 4225·02 4225·62	Weak, broad, hazy line, probably compound.
4227·5	2–3	p Ti. Fe.	4227·40 4227·61	
4229·8	2	Fe.	4229·68 4229·93	
4233·3	5	p Fe. p Cr.	4233·32 4223·50	
4235·4	1–2	Mn.	4235·30 4235·45	
4236·1	3	Fe.	4236·11	Broad, possibly double.
4239·0	3	Fe.	4238·97	
4240·7	1–2	Fe. Un. Cr.	4240·54 4240·62 4240·87	
4242·6	3	p Cr.	4242·54	
4250·3	2–3	Fe.	4250·29	
4250·9	2–3	Fe.	4250·95	
4252·8	4	p Cr.	4252·80	
4254·5	4	Cr.	4254·50	
4256·2	2–3	Fe. Un.	4255·99 4256·37	
4258·6	2–3	? Fe.	4258·48 4258·77	α Cygni line in same position, but in that star cannot be attributed to Fe.
4260·2 4260·7	1–2	Fe.	4260·18 4260·64	

ε Ursæ Majoris. (Kensington.) λ	Int. Max. 10.	Probable Origin Un. = Unknown.	λ of Probable Origin.	Remarks.
4262·1	3–4	p Cr.	4262·15	
4263·3 to 4264·4	2	Ti. Cr. Un. Fe.	4263·29 4264·13 4264·37	Broad hazy line.
4268·0	1	Fe	4267·99	
4269·5	2–3	p Cr.	4269·52	
4271·5	3	Fe.	4271·33 4271·93	
4273·7	1–2	Fe. Zr. Fe. ?	4273·48 4273·64 4274·05	Broad weak line.
4274·9	2–3	Cr.	4274·96	
4275·6	3	Un.		
4278·4	3	Fe. Ti.	4278·39	
4280·6	2	Cr.	4280·56	
4282·8	1–2	Fe. Ca.	4282·57 4283·17	
4284·4	3	p Cr.	4284·38	
4288·2	1–2	Ti. Ni. Ti.	4288·04 4288·15 4288·31	
4290·2	5	Cr p Ti.	4289·89 4290·38	
4292·3	3	Un.	4292·29	
4294·2	3	p Ti.	4294·20	
4296·7	3	p Fe.	4296·72	
4300·2	3–4	p Ti.	4300·21	
4302·1	1	Ti.	4302·09	
4303·3	1	p Fe.	4303·34	
4307·1	1	p Cr.	4307·20	
4308·0	3	Fe. p Ti.	4308·08 4308·10	
4309·5	2	Fe.	4309·54	
4313 0	3-4	p Ti.	4313·03	
4315·1	4 5	p Ti.	4315·14	
4321·1	2–3	p Ti.	4321·20	
4326·0	4–5	Fe.	4325·94	

ε Ursæ Majoris. (Kensington.)		Probable Origin. Un. = Unknown.	λ of Probable Origin.	Remarks.
λ	Int. Max. 10.			
4327·3	2–3	? Fe.	4327·27	
4330·7	2–3	p Ti.	4330·50 4330·87	
4338·1	2	p Ti.	4338·08	
4340·7	10	H.	4340·63	H. γ
4344·4	3	p Ti.	4344·45	
4351·9	3–4	p Fe.	4351·93	
4358·7	1–2	Fe.	4358·67	
4359·8	1–2	Cr.	4359·87	
4363·3	2–3	Cr.	4363·27	
4367·8	2–3	p Ti.	4367·84	
4369·9	2	Fe.	4369·94	
4371·5	1–2	Cr.	4371·44	
4374·9	1–2	p Ti.	4374·90	
4383·7	2–3	Fe.	4383·72	
4385·5	2–3	p Fe.	4385·55	
4387·0	1–2	p Ti.	4387·01	
4388·6	2–3	? Fe.	4388·57	
4391·9	1	? Cr.	4391·92	
4395·2	3	p Ti.	4395·20	
4399·9	2–3	p Ti.	4399·94	
4403·3	2–3	Un.	4403·35	
4404·9	2–3	Fe.	4404·93	
4415·3	2–3	Fe.	4415·29	
4417·0	3	p Fe.	4416·99	
4422·7	2–3	Fe.	4422·74	
4427·4	2–3	Ti. Fe.	4427·27 4427·48	
4430·6	3	Fe.	4430·36 4430·79	
4444·0	2–3	p Ti.	4443·98	
4450·6	2	p Ti.	4450·65	
4455·0	1	Ca.	4454·95	

ε Ursæ Majoris. (Kensington.)		Probable Origin. Un. = Unknown.	λ of Probable Origin.	Remarks.
λ	Int. Max. 10.			
4459·2	2	Ni. Fe.	4459·20 4459·30	
4462·0	3–4	Fe. Fe. Mn.	4461·82 4462·17	
4464·7	2	p Ti. Mn.	4464·62 4464·84	
4466·7	1	Fe.	4466·73	
4468·7	1–2	p Ti.	4468·66	
4469·5	1	Fe.	4469·55	
4472·9	2–3	Fe.	4472·88	
4476·2	3	Fe. Un.	4476·19 4476·25	Rowland gives Ag. for this solar line, but identity very doubtful.
4478·8	2	Un.		
4481·3	7	p Mg.	4481·40	
4484·4	1	Fe.	4484·39	
4485·8	1	Fe.	4485·85	
4489·4	3–4	p Fe.	4489·35	
4491·6	3	p Fe.	4491·57	
4494·7	2–3	Fe.	4494·74	
4499·2	1–2	Cr. Mn. Un.	4498·90 4499·07 4499·31	
4501·5	3	p Ti.	4501·45	
4505·0	2–3	? Fe.	4505·00	Coincident with the weak solar Fe. line 4505·00, but Fe. origin doubtful.
4507·0	1–2	Un.		
4508·5	3	p Fe.	4508·46	
4510·6	1	Un.		
4512·0	3	Cr.	4512·07	
4515·5	5	p Fe.	4515·51	Abnormally strong in this star.
4520·4	3	p Fe.	4520·40	
4522·8	3–4	p Fe.	4522·77	
4525·3	1	Fe.	4525·31	
4527·1	2	Cr. Fe. Ca. ? Ti.	4526·63 4526·73 4527·10 4527·49	

ε Ursæ Majoris. (Kensington.)		Probable Origin. Un. = Unknown.	λ of Probable Origin.	Remarks.
λ	Int. Max. 10.			
4529·3	1–2	Fe. / p Ti. / Un. / Fe.	4528·80 / 4529·60 / 4529·73 / 4529·85	Rather broad line.
4531·1	1–2	Cr. / Co. / Fe.	4530·91 / 4531·12 / 4531·33	
4534·0	4	p Ti.	4534·14	
4536·0	1–2	Ti. / Cr. / Ti.	4535·74 / 4535·88 / 4536·09, 4536·22	
4539·9	2–3	Cr.	4539·95	
4541·4	2–3	p Fe.	4541·46	
4544·8	1	Cr. / Ti.	4544·79 / 4544·86	
4546 2	2	Fe. Cr.	4546·13	
4549·9	6	p Fe. / p Ti.	4549·64 / 4549·81	
4552·7	2	Ti. / Fe.	4552·63 / 4552·73	
4555·2	4	p Cr.	4555·16	
4556·2	4	p Fe. / Fe.	4556·09 / 4556·31	
4558·8	5–6	p Cr.	4558·83	
4563·9	2	p Ti.	4563·94	
4565·8	2–3	Cr. / Co. Fe.	4565·69 / 4565·84	
4568·9	1–2	Fe.	4568·94	
4571·2 / 4572·1	3	Mg. / p Ti.	4571·28 / 4572·16	
4576·5	3	p Fe.	4576·51	
4580·2	2–3	Cr.	4580·23	
4584·0	4	p Fe.	4584·02	Broad, possibly double.
4588·4	3	p Cr.	4588·38	
4590·1	1–2	p Ti.	4590·13	
4592·2	2–3	p Cr.	4592·25	
4596·6	2–3	Cr.	4596·59	
4616·8	3	p Cr.	4616·81	

ε Ursæ Majoris. (Kensington.) λ	Int. Max. 10.	Probable Origin. Un. = Unknown.	λ of Probable Origin.	Remarks.
4619·0	3	p Cr.	4618·97	
4620·7	1–2	Fe.	4620·69	
4625·8	3	Fe. Cr.	4625·23 4626·36	Broad line, probably double.
4629·5	3–4	p Fe.	4629·51	
4634·3	2–3	p Cr.	4634·25	
4635·5	2–3	p Fe.	4635·50	
4637·9	2	Fe	4637·69 4638·19	
4646·3 to 4648·8	3	Cr. Fe. Ni.	4646·35 4647·62 4648·84	Broad band, apparently comprising the bunch of solar lines from 4646–3 to 4648–8.
4651·8	2–3	Cr.	4651·46 4652·34	
4654·7	2	Fe.	4654·67 4654·80	
4657·4	2	p Ti.	4657·38	
4663·7	2	? p Al.	4663·70	
4667·6	3	Fe. Ti.	4667·63 4667·77	
4698·8	1–2	Co. Cr. Ti.	4698·58 4698·64 4698·80 4698·95	
4703·2	2	Mg.	4703·18	
4707·5 to 4710·5	2	Fe. Cr. Ti. Fe. Mn. Fe.	4707·46 4708·20 4709 15 4709·27 4709·90 4710·47	Broad hazy band, including solar group 4707·5 to 4710·5.
4714·6	3	Ni.	4714·60	
4722·2	1–2	Zn.	4722·34	
4727·6	2–3	Fe. Mn.	4727·58 4727·68	
4731·7	2	Fe. ?	4731·65	
4737·3	2	Fe. Cr. Fe. ?	4736·96 4737·54 4737·82	
4756·5	3–4	Cr. Ni.	4756·30 4756·71	

ε Ursæ Majoris. (Kensington.)		Probable Origin. Un. = Unknown.	λ of Probable Origin.	Remarks.
λ	Int. Max. 10.			
4766·4	3	Mn.	4766·05 4766·62	
4812·7	2–3	p Cr.	4812·72	
4824·3	4	p Cr.	4824·33	
4836·4	2	p Cr.	4836·40	
4848·4	4	p Cr.	4848·44	
4861·7	10	H.	4861·53	Hβ.

The spectrum seems to show some curious alterations in relative intensity of individual lines in groups of lines which have a characteristic appearance in other stars. The following examples to illustrate this point may be given:—

1. MANGANESE QUARTET (4030 to 4035).

In stars of the solar, Arcturian, and Procyonian types, this group of lines is quite conspicuous, and has roughly the same characteristic appearance in such types. In ε Ursæ Majoris, however, although there are lines agreeing in position with each line in the quartet, the relative intensities are so altered as to make the group have an altogether different appearance. The two most refrangible lines are quite outstanding in intensity, the other two being so much weakened as to give the appearance for the collective group of two doubles, one strong, the other nearly evanescent, instead of a group of four evidently associated lines.

2. IRON TRIPLET (4045·9 to 4071·9).

In stars of the solar, Arcturian, Procyonian, and Sirian types the triplet is very well marked, there being little difference in intensity between the three individual lines. In ε Ursæ Majoris, however, the two more refrangible lines are well marked, especially 4063·7, while the third, 4071·9, is only of insignificant intensity.

PROTO-IRON QUARTET (4508·5, 4515·5, 4520·4, 4522·8).

In such spectra as those of α Cygni and Sirius—in which the lines are very conspicuous—and in the spectra of Rigel and the Sun, where they are comparatively faint, the individual lines are of about equal intensity. In ε Ursæ Majoris, however, the line 4515·5 is much stronger than any of the others and alters considerably the characteristic appearance of the quartet as it occurs in the stars named. In the chromospheric spectrum, the intensities of the individual lines are affected in a different manner. In this case the line 4520·4 is somewhat weakened, and the line 4522·8 much strengthened. The latter effect may be produced by the combination of the solar—Ti line 4522·97 with the proto-iron line 4522·80.

It may be, of course, that the alteration in appearance of the characteristic groups of lines mentioned in the preceding paragraphs may be brought about by the superposition of strange lines in ε Ursæ Majoris, on some of the lines occurring in the other stars. The collective evidence, however, seems to point to the fact that the different conditions appertaining in the absorbing atmosphere of the star in question has a selective effect on the intensities of some of the lines constituting the groups mentioned.

COMPARISON OF ε URSÆ MAJORIS AND SIRIUS.

(Most marked differences only included in table.)

Although the star under discussion has been classified as Sirian (Sirius) it has also been recognised that there are many points where its spectrum differs in detail from that of Sirius. It therefore seemed desirable to make a careful comparison of the two spectra and record the differences which exist. This has been done, and the lines which vary most strikingly in the two spectra are given in the following list.

An analysis of these differences should throw some light on the relative positions of the two stars in the temperature curve of the Kensington classification.

The first column contains the wave-lengths of the affected lines, the second their intensities in ε Ursæ Majoris, the third and fourth the probable origins of the lines, and the wave-lengths of the probable origins. The last column is reserved for remarks, chiefly on whether the lines in question are stronger or weaker in ε Ursæ Majoris than in Sirius.

MOST STRIKING DIFFERENCES BETWEEN ε URSÆ MAJORIS AND SIRIUS.

ε Ursæ Majoris.		Probable Origin.	λ of Probable	Remarks.
λ	Int. Max. 10.	Un. = Unknown.	Origin.	(Whether stronger or weaker than in Sirius.)
3933·8	6	p Ca.	3933·83	Considerably weaker.
3936·0	3-4	p Fe.	3935·92	„ stronger.
3944·1	1	Al.	3944·16	„ weaker.
3945·2	2–3	Fe.	3945·03 3945·26	Rather stronger.
3956·6	3	Co. Ti. Fe. Fe.	3956·48 3956·60 3956·82	Stronger.
3961·6	1	Al.	3961·67	Weaker.
3968·6	10	p Ca.	3968·63	Weaker.
3970·2		H.	3970·18	More diffuse than in Sirius.
4003·6	1–2	p Cr.	4003·55	Apparently lacking in Sirius.
4015·7	1	p Ni.	4015·76	Much weaker and hazier.

ε Ursæ Majoris.		Probable Origin. Un. = Unknown.	λ of Probable Origin.	Remarks. (Whether stronger or weaker than in Sirius.)
λ	Int. Max. 10.			
4018·3	3	Mn. Fe.	4018·25 4018·42	Stronger.
4022·0	2	Fe.	4022·02	Very weak or lacking in Sirius.
4030·9	5	Mn.	4030·87	Much more prominent.
4033·2	4–5	Mn.	4033·22	,, ,,
4038·1	2–3	p Cr.	4038·10	Stronger.
4044·0	2–3	Fe. Un.	4044·06 4044·14	Considerably stronger.
4048·8	3	p Fe. Mn.	4048·93	,, ,,
4052·1	3	p Cr.	4052·10	Much stronger.
4058·9	1–2	p Cr.	4058·92	Apparently lacking in Sirius.
4071·9	1–2	Fe	4071·91	More diffuse than in Sirius.
4077·9	3–4	p Sr.	4077·88	,, ,, ,,
4082·50	2–3	p Cr.	4082·50	Apparently lacking in Sirius.
4083·8	2	Mn.	4083·78	Weak or lacking in Sirius.
4087·8	2–3	Un.	—	,, ,, ,,
4111·2	3	p Cr.	4111·25	Much stronger.
4113·0	3	Fe.	4113·12	Considerably stronger.
4128·2	1–2	p Si.(II.)	4128·20	Much weaker.
4128·9	3	Un.	4128·89	Quite a pronounced line bordering p Si. 4128·1 in ε Ursæ Majoris. Mere trace only in Sirius.
4131·1	1–2	p Si.(II.)	4131·04	Weaker.
4132·6	5	Un.	4132·69	Much stronger.
4145·9	3–4	p Cr.	4145·91	Considerably stronger.
4154·4	3–4	Fe.	4154·07 4154·67 4154·98	Stronger.
4161·7	3	p Ti.	4161·70	Stronger.
4171·1	3	? Fe. Ti.	4171·07 4171·27	Well-marked in ε Ursæ Majoris. Apparently lacking in Sirius.
4172·2	4	p Ti. Fe.	4172·07 4172·30	Considerably stronger.
4173·6	2–3	p Fe. p Ti.	4173·61 4173·71	,, weaker.
4177·7	1–2	? p Y.	4177·75	Weaker.
4179·0	4	p Fe.	4179·05	Stronger.

ε Ursæ Majoris.		Probable Origin. Un. = Unknown.	λ of Probable Origin.	Remarks. (Whether stronger or weaker than in Sirius.)
λ	Int. Max. 10.			
4182·0	3	Fe. Un.	4181·92 4182·14	Stronger.
4184·2 to 4185·1	2–3	Un. Un. Fe. Cr.	4184·16 4184·47 4185·06	„
4195·6	3–4	Fe.	4195·49 4195·79	Much stronger.
4202·2	2	Fe.	4202·20	Weaker.
4205·2	2	Un.	4205·19 4205·24	Much stronger.
4217·7	2–3	Fe. Cr.	4217·72	Considerably stronger.
4219·5	3	Fe. Un.	4219·52 4219·58	„ „ and sharper.
4224·7 to 4225·6	2	Cr. Fe. p Cr. Fe.	4224·67 4225·02 4225·62	Stronger.
4229·8	2	Fe.	4229·68 4229·93	Apparently lacking in Sirius.
4236·1	3	Fe.	4236·11	Stronger.
4239·0	3	Fe.	4238·97	Considerably stronger.
4252·8	4	p Cr.	4252·80	„ „
4256·2	2	Fe. Un.	4255·99 4256·37	Very weak or lacking in Sirius.
4262·1	3–4	p Cr.	4262·15	Stronger.
4269·5	2–3	p Cr.	4269·52	„
4278·4	3	Fe. Ti.	4278·39	„
4284·1	3	p Cr.	4284·38	Considerably stronger.
4292·3	3	Un.	4292·29	Well marked in ε Ursæ Majoris, nearly evanescent in Sirius.
4296·7	3	p Fe.	4296·72	Weaker.
4302·1	1	Ti.	4302·09	„
4308·0	3	Fe. p Ti.	4308·08 4308·10	Rather weaker.
4321·1	2–3	p Ti.	4321·20	Considerably stronger.
4327·3	2 3	? Fe.	4327·27	Apparently lacking in Sirius.
4344·1	3	p Ti.	4344·45	Stronger.
4351·9	3–4	p Fe.	4351·93	Considerably hazier than in Sirius.
4367·8	2–3	p Ti.	4367·84	„ stronger.
4369·9	2	Fe.	4369·94	„ stronger.

ε Ursæ Majoris.		Probable Origin. Un. = Unknown.	λ of Probable	Remarks.
λ	Int. Max. 10.		Origin.	(Whether stronger or weaker than in Sirius.)
4395·2	3	p Ti.	4395·20	Weaker and hazier.
4422·7	2–3	Fe.	4422·74	Considerably stronger.
4427·4	2–3	Ti. Fe.	4427·27 4427·48	„ „
4430·6	3	Fe.	4430·36 4430·79	„ „
4462·0	3–4	Fe. Fe. Mn.	4461·82 4462·17	Much stronger.
4466·7	1–2	Fe.	4466·73	Very weak or lacking in Sirius.
4468·7	1–2	p Ti.	4468·66	Considerably weaker.
4472·9	2	Fe.	4472·88	Apparently lacking in Sirius.
4476·2	3	Fe. Un.	4476·19 4476·25	Considerably stronger.
4478·8	2	Un.	—	Apparently lacking in Sirius.
4505·0	2–3	? Fe.	4505·00	Very weak or lacking in Sirius.
4512·0	3	Cr.	4512·07	Much stronger.
4515·5	5	p Fe.	4515·51	„ „
4552·7	2	Ti. Fe.	4552·63 4552·73	Apparently lacking in Sirius.
4554·2	—	Ba.	4554·21	Sharp line in Sirius ; lacking in ε Ursæ Majoris.
4555·2	4	p Cr.	4555·16	Much stronger.
4558·8	6	p Cr.	4558·83	„
4580·2	2–3	Cr.	4580·23	Stronger.
4590·1	1–2	p Ti.	4590·13	„
4592·2	2–3	p Cr.	4592·25	„
4596·6	2–3	Cr.	4596·59	„
4616·8	3	p Cr.	4616·81	Considerably stronger.
4619·0	3	p Cr.	4618·97	Stronger.
4625·8	3	Fe. Cr.	4625·23 4626·36	Weak or lacking in Sirius
4812·7	2–3	p Cr.	4812·72	Stronger.
4824·3	5	p Cr.	4824·33	„
4836·4	2–3	p Cr.	4836·40	„
4848–4	5	p Cr.	4848·44	„

ANALYSIS OF THE ORIGINS OF LINES AFFECTED IN PASSING FROM ε URSÆ MAJORIS TO SIRIUS.

A glance through the remarks in the preceding table will show that there are comparatively few lines occurring in ε Ursæ Majoris which are lacking in Sirius, and only one line (Ba 4554·2) of marked intensity in Sirius which is absent from ε Ursæ Majoris. It will be of interest to analyse the origins of the lines which show variations in the two spectra. For this purpose it will be best to divide them up into several groups as follows:—1. Lines occurring in ε Ursæ Majoris, but very weak or lacking in Sirius. 2. Lines "much stronger," "considerably stronger," or "stronger" in ε Ursæ Majoris. 3. Lines "much weaker," "considerably weaker," or "weaker" in ε Ursæ Majoris than in Sirius. 4. Lines occurring in Sirius but apparently lacking in ε Ursæ Majoris.

TABLE SHOWING THE NUMBERS AND PERCENTAGES OF LINES OF INDIVIDUAL ELEMENTS AFFECTED IN PASSING FROM THE SPECTRUM OF ε URSÆ MAJORIS TO THAT OF SIRIUS.

Substance.	Total Number of Lines included in "probable origins" in ε Ursæ Majoris.	Lines occurring in ε Ursæ Majoris but very weak or lacking in Sirius.		Lines "Much Stronger," "Considerably Stronger," or "Stronger" in ε Ursæ Majoris than in Sirius.		Lines "Much Weaker," "Considerably Weaker," or "Weaker" in ε Ursæ Majoris than in Sirius.		Lines occurring in Sirius but lacking in ε Ursæ Majoris.	
		No. of Lines.	Percentage.	No. of Lines.	Percentage.	No. of Lines.	Percentage.	No. of Lines.	Percentage.
Al.	2					2	100		
Ba.	0							1	100
p Ca.	2					2	100		
Co.	6	1	17	1	17				
Cr.	37			6	16				
p Cr.	30	3	10	18	60				
Fe.	142	9	6	25	18	2	2		
p Fe.	24			4	17	2	8		
Mn.	16	1	6	4	25				
p Ni.	3					1	33		
p Si.	2					2	100		
Ti.	18	2	11	3	17	1	6		
p Ti.	37			6	16	4	11		
p Y.	1					1	100		
Un.	44	6	14	8	18				

It will be seen from the table that, amongst the strengthened lines in ϵ Ursæ Majoris, proto-chromium lines figure most prominently, 70 per cent. of these being stronger in ϵ Ursæ Majoris than in Sirius.

The lines weaker in ϵ Ursæ Majoris than in Sirius are few in number and include the only two lines of proto-calcium, aluminium, and proto-silicium respectively.

The predominance of proto-chromium lines has suggested a special comparison of these in ϵ Ursæ Majoris with the p Cr. lines as they occur in Sirius and α Cygni. These stars, previously to the investigation of ϵ Ursæ Majoris, had been found to show the proto-chromium lines more prominently than any type stars representing other levels of the Kensington temperature curve.

The comparison is given in the following table. A glance down the intensity columns for the three stars will show that the intensities in ϵ Ursæ Majoris are, in general, distinctly higher than in Sirius and α Cygni, in which two stars the intensities are very similar to each other.

ENHANCED LINES OF CHROMIUM.

(Relative intensities in ϵ Ursæ Majoris, Sirius and α Cygni.)

Enhanced Cr. Lines λ.	Intensity.		Intensity.			Remarks.
	Spark. Max. 10.	Arc. Max. 10.	ϵ Ursæ Majoris. Max. 10.	Sirius. Max. 10.	α Cygni. Max. 10.	
3905·66	6	0	3	4	4	Stellar line possibly due partly to Si.
3979·66	5–6	0	2–3	2	2–3	
4003·55	4	0	2	—	—	
4012·63	6–7	2	5	4	4–5	Stellar line partly due to p Ti.
4038–10	4–5	0	2–3	1–2	1	
4052·10	3	0	3	1	2	
4058·92	5	3–4	1–2	—	—	
4071·07	4	0	1–2	1	—	
4082·50	2–3	0	2–3	—	<1	
4111·25	4	0	3	1	2	
4145·91	6	0	3–4	2	1–2	
4225·02	4	0	2–3	1	1–2	Stellar line possibly compound.
4233·50	2–3	0	5	4–5	7	Stellar line due chiefly to p Fe.
4242·54	6–7	0	3	3	4	
4252·80	3	0	4	2–3	2	
4262·15	5–6	0	3–4	2–3	3–4	

Enhanced Cr. Lines λ.	Intensity.		Intensity.			Remarks.
	Spark. Max. 10.	Arc. Max. 10.	ε Ursæ Majoris. Max. 10.	Sirius. Max. 10.	α Cygni. Max. 10.	
4269·52	2	0	2–3	2	1	
4284·38	3–4	0	3	2	2	
4307·20	2–3	0	1	—	—	
4555·16	5–6	1	4	1	2	
4558·83	10	1	6	3	5	
4588·38	10	1	3	2–3	4	
4592·25	4–5	0	2–3	2	3	
4616·81	3–4	0	3	1–2	2	
4618·97	8	0	3	2	3	
4634·25	8	0	2–3	2–3	3	
4812·70	2–3	0	2–3	1	2	
4824·33	8	0	5	3	4	
4836·40	2–3	0	2–3	1	2	
4848·44	6	0	5	3	4	

COMPARISON OF THE KENSINGTON NEGATIVES OF ε URSÆ MAJORIS.

Only three photographs have been obtained with the two 6-inch objective prisms which are satisfactory enough for comparison. These have been intercompared but no evidence is forthcoming to show that there are any definite changes either in the positions of the lines or in their relative intensity. It will be desirable, however, to get a series of satisfactory spectra over an extended period before the constancy of the spectrum can be verified.

POSITION OF ε URSÆ MAJORIS IN THE STELLAR CLASSIFICATION.

The great width of the hydrogen lines in this star undoubtedly places it on the descending side of the Kensington stellar temperature curve. The general appearance of the metallic lines tends to show that it should come between the Sirian and Procyonian groups. The solar lines are, in general, more pronounced than in Sirius and less so than in Procyon. Moreover, there are several fairly well marked lines common to ε Ursæ Majoris and Procyon which are very weak or lacking in Sirius.

The lines of one or two elements, notably Al and p Ca, seem to be of anomalous behaviour, if we assume the star's position to be as above-mentioned. Thus the p Ca lines thicken in coming down the temperature curve from

Markabian, through Sirian and Procyonian, to Arcturian types. As the p Ca lines are slightly weaker in ϵ Ursæ Majoris than in Sirius, from the behaviour of these lines alone ϵ Ursæ Majoris would be placed above the Sirian and between that group and the Markabian. Similarly the aluminium lines, which in this star are weaker than in Sirius, strengthen in passing from the Markabian to the Arcturian group, so from the behaviour of these lines also it would appear that ϵ Ursæ Majoris should come a little above Sirius.

The behaviour of the p Si (II.) lines, however, seems to be an effectual bar to placing ϵ Ursæ Majoris above Sirius. At the next higher level than the Sirian group, viz., Rigelian (ascending) and Markabian (descending), the p Si (II.) lines are quite as conspicuous as in Sirius. At these stages, too, the helium lines occur. In ϵ Ursæ Majoris, however, there is no trace of helium and the p Si (II.) lines are very much weaker than in the Sirian, Rigelian, or Markabian types, and approach more closely to the intensities of the same lines in the Procyonian group.

GENERAL CONCLUSIONS.

Although there are a few abnormalities in the behaviour of the lines of certain elements, the bulk of the evidence is in favour of the star being placed between the Sirian and Procyonian groups on the stellar temperature scale.

The enhanced lines of chromium are better developed in this star than in any other hitherto examined. From this point of view ϵ Ursæ Majoris can be used as a sub-class between the Sirian and Procyonian groups.

Several well-known groups of lines which have a characteristic appearance in other stars are here, by the alteration in relative intensity of some of the individual lines, made to lose their usual appearance. Examples:—Fe. triplet (4045–4071), Mn. quartet (4030–4035) and p Fe. quartet (4508·5 4522·8). This selective effect on some of the lines constituting the different groups is probably due to the different conditions prevailing in the absorbing atmosphere of the star.

From a comparison of the few satisfactory photographs of the spectrum which have been obtained, there is no evidence from the doubling or broadening of the lines that the star is a spectroscopic binary.

III.

NITROGEN LINES IN STELLAR SPECTRA.

The presence of certain strong nitrogen lines in stellar spectra was established in 1899 by comparison of Kensington laboratory and stellar photographs, and various references to nitrogen in stars have since been made by different spectroscopists. Up to the present, however, these references have been somewhat of a patchy nature, only a few of the stronger lines of nitrogen having been considered in this connection.

Recent research at Kensington has shown that some lines of nitrogen are of abnormal behaviour under varying conditions of current, and also that these lines occur conspicuously in stellar spectra of the Alnitamian type. These results were embodied in a paper: "On the Origin of Certain Lines in the Spectrum of ϵ Orionis," and, as they showed the increased importance of nitrogen in a survey of stellar spectra, it was thought advisable to institute a more comprehensive study of the relation of the nitrogen spectrum, as a whole, to various stellar spectra.

Since the discovery of the presence of nitrogen lines in stellar spectra, better photographs of the latter have been obtained at Kensington, which enable us to undertake a more detailed comparison of the stellar and laboratory lines, and this has recently been done.

Before giving the results of this comparison it will be well to refer briefly to previous publications in which the relation of nitrogen lines to stellar lines is mentioned. These references will be given in chronological order.

In a Kensington publication,* "On the Order of Appearance of Chemical Substances at different Stellar Temperatures," which was read at the Royal Society on February 23, 1899, the following occurs: "There is evidence that the "strongest lines of nitrogen at λ 3995·2 and λ 4630·9 make their appearance "in stars at about the temperature of α Crucis. These lines appear from Rigel "to ζ Orionis in the upward series, and are present in stars at the α Eridani "stage in the downward." (In a map showing the behaviour in stellar spectra of characteristic lines of various elements, nitrogen is represented by the line 3995·2.)

Note.—In a previous publication by Mr. McClean on "The Spectra of Southern Stars" the line 3995·1 is referred to as "air." No mention is made of its being due to nitrogen. In the same paper the β Crucis line 4630·9, which is undoubtedly due to nitrogen, has no origin attached to it.

In a paper† "On the Presence of Oxygen in the Atmospheres of certain Fixed Stars," read at the Royal Society on April 27, 1899, Sir David Gill, after saying (p. 205) "there remains not the slightest doubt that all the stronger

* Roy. Soc. Proc., vol. 64, p. 398.

† Roy. Soc. Proc., vol. 65, p. 205.

" oxygen lines are present in the spectrum of β Crucis, at least between λ 4250 " and 4575," goes on to say, " It is almost equally certain that there is no trace of true nitrogen lines in this spectrum." In this he was probably referring to the limited region of the spectrum which he investigated. That the strong nitrogen lines 3995·1, 4447·2, 4630·7 occur in the β Crucis spectrum there can be no question, as a reference to McClean's tabular list of lines† and his reproduction of the β Crucis spectrum will clearly show.

In another Kensington publication, " On the Chemical Classification of the Stars,"* read at the Royal Society on May 4, 1899, reference is again made to an enquiry into the varying intensities in the different stars of the lines of, amongst other chemical elements, nitrogen. In this paper also, in a " Classification of Stars into Genera depending upon their Chemistry and Temperature," nitrogen is given as occurring in stars of the Alnitamian, Crucian, Taurian, Rigelian and Achernian groups of the Kensington classification.

In the " Astronomische Nachrichten " of date May 6, 1899 (Bd. 149, No. 3565), there is a reprint of the Kensington publication " On the Order of Appearance of Chemical Substances at different Stellar Temperatures," which has been already referred to in this paper in its connection with nitrogen lines. Incidentally it may be mentioned that in the same number of the " Astronomische Nachrichten," Sir William Huggins has a short note confirming McClean's previous statement as to the presence of lines of oxygen in stellar spectra.

In a subsequent " Astronomische Nachrichten," of date July 31 (Bd. 150, No. 3583), Huggins has a short note on " Nitrogen in some Helium Stars." In this he says:—" I wish to add to my note (Astr. Nachr. 3565, p. 231) on the " presence of oxygen in stars characterised by strong helium lines, that in the " spectra of some of these stars, notably Bellatrix and Rigel, as well as in some " other stars there is a dark line at the position of the strongest line of nitrogen " at λ 3995. In Bellatrix there are also lines corresponding with some other " strong lines of nitrogen. There seems to me a high probability that nitrogen is " really present as well as oxygen."

In this note Huggins does not refer to either of the previously published statements as to the occurrence of nitrogen lines in stellar spectra.

In a " Catalogue of 470 of the Brighter Stars " (published by the Solar Physics Committee, 1902) the lines in the spectra of various type stars are tabulated. With regard to nitrogen, in the spectra of Rigel (Rigelian) and Tauri (Taurian) the line 3995 is attributed to that element. In the spectrum of Bellatrix (Crucian) the following lines are given as being probably due to nitrogen, 3995·1, 4237·0, 4241·8, 4630·9, and various other lines are recorded as being " possibly " due to nitrogen, the evidence for this origin having been thought suggestive but not conclusive. In the spectrum of ϵ Orionis (Alnitamian) line 3995·1 is recorded as probably due to nitrogen, and several others are given as

* Roy. Soc. Proc., vol. 65, p. 189.

† " Spectra of Southern Stars," 1898.

"possibly" due to the same element. For the type stars representing lower groups than the Crucian on the temperature curve no evidence was forthcoming for the occurrence of nitrogen lines in their spectra.

In a recent Kensington publication,* "On the Origin of Certain Lines in the Spectrum of ϵ Orionis (Alnitam)" it has been shown that some well-marked lines —hitherto of unknown origin—are due to nitrogen. These are nitrogen lines which occur only weakly in the ordinary spark spectrum, but which increase greatly in intensity relatively to other nitrogen lines when particular conditions of current are employed.

The table at the end of this paper gives the strongest lines of nitrogen as recorded by Exner and Haschek and Neovius, and also the strongest lines as shown in the Kensington nitrogen vacuum-tube spectrum.

The two former refer to the spark at atmospheric pressure. Owing to the different scales of intensity employed by different observers it is somewhat difficult to decide on the lower limit of intensity for the lines to be included in the comparison table. It is thought best to make the numbers of lines in each list as equal as possible irrespective of whether the lines included are identical in the three records. In this way, lines from Exner and Haschek's lists of intensity 3 and upwards are included, from Neovius intensity 5 and upwards, and from the Kensington photograph, lines which have at least an intensity of 4.

As will be seen from the table, most of the lines are common to the three lists, but there are a few which only occur in one. In these latter cases it does not follow that the lines have not been recorded as nitrogen lines by other observers, but the intensity as given by them is too low to accept them as amongst the strongest lines in their respective records.

The table also indicates which of the nitrogen lines have been traced in the spectra of β, γ, κ, ϵ, ζ, and ι Orionis.

The order in which the stars have been placed in the table has been influenced partly by a study of the nitrogen lines themselves, and partly by lines of other elements. The point in view has been to get a regular sequence from a temperature point of view. In the Kensington classification β Orionis (Rigelian), γ Orionis (Crucian), and ϵ Orionis (Alnitamian) have been placed in the order given, ϵ Orionis being highest of the three on the temperature curve.

As κ, ζ, and ι Orionis are all included in the Alnitamian group, it remained to place these and ϵ Orionis in their proper order. From a study of the lines of various elements represented in the spectra, it has been found that κ and ϵ show close agreement in their spectra, but κ approaches the Bellatrix spectrum more closely than does ϵ Orionis. In the same way ζ and ι Orionis agree closely, but ι Orionis—especially from the intensity of the proto-hydrogen lines, which are there stronger—must be placed slightly higher up the scale.

* Roy. Soc. Proc., vol. 82, p. 532.

A glance at the table will show that there is scarcely a line of any importance in the nitrogen spectrum which has not been traced in Bellatrix, and also that, in general, the nitrogen lines attain their maximum intensity at the Bellatrix (Crucian) level.

At the Rigelian stage the only two lines of nitrogen which are with certainty present are 3995·1, 4630·7, perhaps the two most outstanding lines in the ordinary nitrogen spark spectrum in the region considered. These intensify at the Bellatrix stage and then decline in intensity through the succeeding spectra at higher levels of the temperature curve. Most of the other nitrogen lines show a similar decline in intensity.

As to the lines 4097·4, 4379·8, it will be seen that these do not attain their maximum until the κ or ϵ Orionis stage is reached, and then weaken through the higher ζ and ι stages. These are the two nitrogen lines which have been recently shown* to have an abnormal behaviour in laboratory spectra when certain conditions of current are introduced.

As the nitrogen lines vary in character, some being comparatively sharp while others are hazy, it is of interest to note that, in general, the hazy lines in laboratory spectra are also of a hazy or diffuse nature in the stellar spectra.

* Roy. Soc. Proc., vol. 82, p. 532.

NITROGEN LINES IN STELLAR SPECTRA.

Exner and Hasehek.		Neovius Spark at Atmos. pres.		Kensington. (Vacuum Tube.)		Nature of Line in Kensington photograph.	Intensity in Stellar Spectra. Max. 10.						Remarks.
λ	Int. Max. 50.	λ	Int. Max. 12.	λ	Int. Max. 10.		Rigel.	Bellatrix.	κ Orionis.	ε Orionis.	ζ Orionis.	ι Orionis.	
3919·21	10	3919·2	?	3919·2	4	Sharp		3	2	1–2			Oxygen line here also. Stellar line probably compounded by the two.
3940·20	3							<1					
3956·04	6	3956·1	7	3956·0	4	,,		1	1				
3995·26	50	3995·2	12	3995·3	8	,,	2	4	2–3	1–2	1	1	
4025·77	3						?	?	?	?	?	?	Too near strong helium line 4026·3 to decide whether in stellar spectra.
4035·07	4	4035·2	5	4035·1	5	Hazy		2–3	2	1	<1		Hazy also in stellar spectra.
4041·48	5	4041·5	6	4041·5	7	,,		2–3	1–2	1	<1		,, ,, ,,
4097·43	3		8	4097·4	4	Sharp		1–2	6	6	3–4	3–4	Nitrogen line of abnormal behaviour. *See* Roy. Soc. Proc., vol. 82, page 532.
4103·46	3						?	?	?	?	?	?	Too near strong Hδ line to decide definitely whether in stellar spectra.
		4134·2	6					1	1				
4146·03	4							<1	1	1			
		4152·0	5										
4176·16	3	4176·7	5	4176·2	4	Hazy		1		?			
4228·56	3	4228·9	6	4228·6	4	,,		1					

4236·93	5	4237·0	6	4236·9	6	Hazy		2	1	1			
4241·94	5	4242·1	6	4241·9	8	„		2–3	1	1			
				4379·8		Sharp		1	2	3	1–2		Nitrogen line of abnormal behaviour. *See* Roy. Soc. Proc., vol. 82, page 532.
		4426·1	5					1					
				4432·9	8	„		1–2		1			
4447·23	20	4447·3	12	4447·2	8	„		3	1–2	1			
		4507·7	6					1		1–2			
		4530·3	6	4530·1	8	Hazy		3		1			Hazy line in Bellatrix.
				4552·6	5	„		5–6	5–6	5	2	1–2	This line in Orion star spectra is chiefly due to Si (III.) 4552·8.
4601·67	5	4601·3	9	4601·7	7	Sharp		2	<1	<1			
4607·34	4	4607·2	8	4607·3	6	„		2	1	<1			
4614·05	3	4614·2	8	4614·1	5	„		2	<1	<1			
4621·57	4	4622·0	9	4621·6	6	„		2	1	<1			
4630·73	15	4630·9	12	4630·7	10	„	1–2	3–4	3	2–3	1–2	1–2	
4643·27	5	4643·4	9	4643·3	7	„		2	<1	<1			Bellatrix line probably compounded of O 4641·9 and N 4643·3.

IV.

SECOND LIST OF ENHANCED LINES.

INTRODUCTION.

In 1906 a series of "Tables of Wave-Lengths of Enhanced Lines" was published by the Solar Physics Committee. In the introduction to this, a general history was given of the previously published results in connection with the subject of enhanced lines, and the relation of these lines to celestial spectra. A description was also given of the instruments employed in the work, and the method of reduction of the lines. The elements dealt with in the publication mentioned were aluminium, bismuth, caesium, chromium, cobalt, copper, indium, iron, lanthanum, lead, magnesium, manganese, molybdenum, nickel, potassium, rubidium, ruthenium, silver, strontium, thallium, thorium, tin, titanium, vanadium, yttrium, zinc, zirconium.

The further list given in the present publication comprises the following elements:—Arsenic, barium, beryllium, cadmium, cerium, gold, iridium, lithium, platinum, selenium, tellurium, tungsten.

Samples of compounds of gadolinium, neodymium, praseodymium, samarium, and ytterbium were obtained; but when it was found that their arc spectra were full of lines due to impurities, it was not thought worth while to photograph their spark spectra until purer samples could be secured.

Attempts have been made to obtain other chemical elements of a rarer kind, but owing to lack of funds these more expensive elements or their compounds have had to be omitted from the enquiry.

In this further research the general methods of work have been identical with those indicated in the previous publication.

ARSENIC.

Kensington.			Exner and Hasehek.		
	Intensity.			Intensity.	Remarks.
λ	Spark. Max. 10.	Arc. Max. 10.	λ	Spark. Max. 100.	
3922·59	5	0	3922·60	100	
4037·09	4	0	4037·18	30	

BARIUM.

Kensington.			Exner and Haschek.			Remarks.
	Intensity.			Intensity.		
λ	Spark. Max. 10.	Arc. Max. 10.	λ	Spark. Max. 1,000.	Arc. Max. 500.	
3892·00	7	6	3892·42 *	500	20	* E. and H. give arc λ as 3892·00.
4130·80	8	6–7	4130·91	800	30	
4554·21	10	8-9	4554·21	1000	500	
4934·24	6–7	5				Outside E. and H.'s limits.

BERYLLIUM.

Kensington.			Exner and Haschek.		Remarks.
	Intensity.			Intensity.	
λ	Spark. Max. 10.	Arc. Max. 10.	λ	Spark. Max. 20.	
4572·9	6	0	4572·88	8	

CADMIUM.

Kensington.			Exner and Haschek.		Eder and Valenta.		Remarks.
	Intensity.			Intensity.		Intensity.	
λ	Spark. Max. 10	Arc. Max. 10.	λ	Spark. Max. 100.	λ	Spark. Max. 10.	
4415·90	6	0	4415·91	20	4415·9	10	

CERIUM.

A comparison of the grating spark spectrum of cerium with the arc spectrum indicates about forty apparently enhanced lines. In the reduction of the wave-lengths of these lines from a direct comparison with the solar spectrum, it was found that they agreed closely in position with lines of yttrium and lanthanum. On comparing the spark spectra of these two elements with that of cerium it was seen that all the apparently enhanced lines in the latter spectrum were due to either yttrium or lanthanum. The cerium spark spectrum, therefore, contains no genuine lines which are relatively stronger than in the arc.

GOLD.

Kensington.			Exner and Haschek.		Eder and Valenta.		Remarks.
	Intensity.			Int.		Int.	
λ	Spark. Max. 10.	Arc. Max. 10.	λ	Spark. Max. 20.	λ	Spark. Max. 10.	
3898·0	6	3	3898·05	10	3898·03	10s	
3909·6	1	0	3909·54	2	3909·6	3	
3916·2	1	0	3916·1	1	3916·15	6	
3927·8	1–2	0	3927·8	1	3927·82	3	
3959·3	2–3	0	3959·29	2	3959·35	5s	
3976·8	1	0	3976·75	1	3976·80	3	
3979·7	1	0	3979·70	1	3979·72	3	
4016·2	3	0	4016·20	5	4016·27	8	
4041·1	3	2	4041·10	2			
4053·0	3–4	0	4052·98	6	4053·0	6s	
4065·2	7	6	4065·22	10	4065·20	10s	
4084·3	2	0	4084·29	2	4084·31	4s	
4172·9	1	0	4172·93	1	4172·9	2b	
4315·3	4	2	4315·30	5	4315·34	8s	
4395·6	1	0	4395·6	1	4395·72	3n	Very hazy line
4420·7	1	0	4420·81	2	4420·69	3s	
4437·5	2	trace	4437·50	3	4437·37	4s	
4488·5	4–5	2	4488·47	4	4488·43	8s	
4559·0	1	0			4559·05	6b	
4587·9	2	0	4588·0		4587·91	7b	Hazy line.
4792·8		4			4792·79	8b	

IRIDIUM.

Although the spark spectrum of this element shows a number of genuine iridium lines, not one of them is stronger in the spark than in the arc.

LITHIUM.

The lithium spectra show no lines which are stronger in the spark than in the arc.

PLATINUM.

Kensington.			Exner and Haschek.		Remarks.
	Intensity.			Int.	
λ	Spark Max. 10.	Arc. Max. 10.	λ	Spark Max. 15.	
3875·85	6	5			
3923·15	10	9			
3953·15	1–2	0	3953·15	1	
3970·22	7	2	3970·21	3	
3999·02	1–2	0			
4014·48	2	trace	4014·46	1	
4021·41	1–2	0	4021·40	1	
4023·96	2–3	0	4023·96	1	
4034·26	3–4	trace	4034·32	1	
4044·48	2	0	4044·50	1	
4045·45	1–2	0	4045·45	1	
4046·60	7	2–3	4046·60	6	
4061·78	5–6	1–2	4061·81	2	
4105·60	2	0	4105·60	1	
4134·45	2	0	4134·45	1	
4148·43	3–4	trace	4148·45	1	
4156·27	2	0			
4159·23	2–3	0			
4194·35	1–2	0			
4223·85	3	0	4223·85	1	
4288·54	3–4	0	4288·54	2	
4346·80	2–3	0	4346·79	1	
4372·10	4	0	4372·09	1	
4399·30	1–2	0	4399·3	1	
4425·20	2	0	4425·2	1	
4457·19	1	trace	4457·21	2	
4471·77	2–3	0	4471·82	1	
4482·19	2–3	0			
4514·30	6–7	3	4514·32	3	

SELENIUM.

(There are no really well-defined sharp lines of this element, and the wave-lengths may possibly have an error of ±0·1 tenth-metre.)

Kensington.			
λ	Intensity.		Remarks.
	Spark Max. 10.	Arc.	
3836·2	2–3	0	Fairly sharp.
3877·3	4	0	,,
4002·8	2	0	Hazy.
4008·8	2	0	,,
4020·0	2	0	,,
4030·2	4	0	Rather hazy.
4110·0	4	0	Hazy.
4127·6	3	0	,,
4130·3	5	0	Rather hazy.
4133·7	2–3	0	,,
4138·1	3	0	Broad and hazy.
4153·2	3	0	,, ,, Possibly double.
4169·2	4	0	Sharp.
4176·5	10	0	Strong but hazy
4182·4	10	0	,, ,,
4195·1	2–3	0	Fairly sharp.
4213·6	7	0	Hazy.
4216·3	2	0	Weak and hazy.
4230·2	2	0	Fairly sharp.
4249·1	1	0	Weak and hazy.
4280·6	2–3	0	Rather hazy.
4321·1	6	0	Fairly sharp.
4383·0	8	0	Strong, fairly sharp.
4401·2	6	0	Fairly sharp.
4449·3	3	0	Sharp.
4468·1	1	0	Fairly sharp.

Kensington.			
λ	Intensity. Spark Max. 10.	Arc.	Remarks.
4516·4	2–3	0	All fairly well defined lines.
4564·1	6	0	
4604·4	9	0	
4618·9	4	0	
4648·6	9	0	
4741·5	3	0	
4763·9	4	0	
4840·9	4	0	
4845·4	6	0	

TELLURIUM.

Kensington.			Exner and Haschek.		Remarks.
λ	Intensity. Spark. Max. 10.	Arc.	λ	Int. Spark. Max. 20.	
3841·9	1	0	3842·2	1	
3918·6	5	0			
3931·2	2-3	0			
3936·0	3	0			
3947·9	4	0	3948·0	1	
3964·4	2	0			
3968·9	5	0			
3976·1	4	0	3976·1	1	
3981·9	4	0	3981·9	1	
3984·7	4	0	3984·8	1	
4006·8	10	0	4006·8	2	
4011·9	4	0	4011·9	1	
4049·1	4	0	4049·2	1	
4055·0	5	0	4054·9	1	
4062·1	10	0	4062·1	1	
4073·7	4	0	4073·8	1	

Kensington.			Exner and Haschek		Remarks.
	Intensity.			Int.	
λ	Spark. Max. 10.	Arc.	λ	Spark. Max. 20.	
4075·0	2–3	0	4075·0	1	
4123·1	3	0			
4127·4	2–3	0			
4152·1	2	0			
4163·7	2–3	0			
4170·1	4	0			
4181·8	3	0			
4220·8	5	0	4220·7	1	
4231·7	2	0			
4260·6	4	0			Broad and hazy.
4294·0	3	0			
4302·2	5	0	4302·3	1	
4325·7	1–2	0			
4355·8	4–5	0	4355·8	1	
4361·3	3	0	4361·4	1	
4364·5	2–3	0	4364·5	1	
4370·7	2–3	0			
4377·2	4	0	4377·2	1	
4390·0	2–3	0			
4435·0	5	0	4435·1	1	
4480·5	3	0			Broad and hazy.
4546·1	3	0			
4603·5	4–5	0	4603·5	1	Broad and hazy.
4665·3	4	0			
4688·7	3–4	0			Broad and hazy.
4706·5	3–4	0			
4729·8	3	0			

TUNGSTEN.

The spark spectrum of this element shows no lines which are stronger than the corresponding lines in the arc.

V.

LINES OF SIMPLE AND DEFINITE ORIGIN SUITABLE FOR MEASUREMENT IN RADIAL-VELOCITY WORK ON VARIOUS STELLAR TYPES.

INTRODUCTION.

The work of stellar classification at South Kensington has necessitated a minute enquiry, not only into the wave-lengths, but the probable origins of the various stellar lines. One result has been that many have been found to have complex, some simple, origins.

In addition to published records there is a large mass of unpublished matter, and it has been thought desirable to extract from the various records of stellar spectra the most prominent lines of simple origin and publish them for the benefit of line-of-sight observers.

In the selection of lines for use in radial-velocity determinations, the chief consideration should be the simplicity or purity of the lines—that is, blends should be avoided as much as possible—and there should be practically no doubt as to the real origin of the lines. Reference to various publications relating to this class of spectroscopic work shows that in many cases undoubted blends have been used for measurement, while in a few cases apparently erroneous identifications have been given for adopted lines.

The lines in the following table have been extracted from the records of spectra representing various groups of the Kensington classification. They comprise the Polarian, Cygnian, Rigelian, and Alnitamian groups of the ascending side of the stellar temperature curve, and the Algolian, Markabian, Sirian, Procyonian, and Arcturian on the descending side. These are the only groups for which suitable spectra are available.

Only lines which are of simple origin, and of whose identification there is no doubt, have been selected. There should be no difficulty in getting comparisons for the stellar spectra which will show the actual laboratory lines matched against their stellar counterparts.

The dispersion of the photographs from which the lines have been taken is such that the distance from K to Hβ is 3·8 inches or 9·6 centimetres. With this dispersion all the stellar lines given are easily measurable and are not interfered with in the slightest degree by adjacent lines. With considerably less dispersion it is quite likely that a few of them—especially in such stars as Procyon and Arcturus, which have a great number of lines—would not be distinctly separable from neighbouring lines, but it seems futile to hope for trustworthy results in radial-velocity work where spectra of much less dispersion than that mentioned are employed.

The majority of the lines included in the table occur in the solar spectrum, and in such cases Rowland's wave-lengths for the solar lines have been adopted.

For such lines as those of helium, asterium, proto-silicium, proto-magnesium, proto-nickel, and proto-carbon, which do not occur in the Fraunhoferic spectrum—or, if so, only as extremely weak and unauthenticated lines—care has been taken to give the most trustworthy wave-lengths which have been recorded, or are otherwise available, of the laboratory equivalents of the stellar lines.

The wave-lengths are given to the nearest hundredth of an Ångström unit, and are all on Rowland's scale. That is to say, they are not corrected to Fabry and Buisson's recently published series of standard iron lines which are, between λλ 3,900 and 4,800 from 0·147 to 0·192 tenth-metre lower in wave-length than Rowland's values for the corresponding lines.

TABLES GIVING WAVE-LENGTHS AND ORIGINS OF SELECTED LINES FOR VARIOUS STELLAR TYPES.

POLARIAN (γ CYGNI).

Wave-Length.	Origin.	Wave-Length.	Origin.
4028·50	Proto-titanium.	4274·96	Chromium.
4045·98	Iron.	4296·74	Proto-iron.
4063·76	Iron.	4318·82	Calcium.
4071·91	Iron.	4383·72	Iron.
4077·89	Proto-strontium.	4404·93	Iron.
4163·82	Proto-titanium.	4415·29	Iron.
4202·20	Iron.	4481·40	Proto-magnesium.
4222·38	Iron.	4501·45	Proto-titanium.
4226·90	Calcium.	4554·21	Barium.
4254·51	Chromium.	4584·02	Proto-iron.

CYGNIAN (α CYGNI).

3933·83	Proto-calcium.	4303·34	Proto-iron.
3968·63	Proto-calcium.	4351·93	Proto-iron.
4028·50	Proto-titanium.	4443·98	Proto-titanium.
4045·98	Iron.	4481·40	Proto-magnesium.
4067·27	Proto-nickel.	4508·46	Proto-iron.
4131·04	Proto-silicium (II.).	4515·51	Proto-iron.
4242·54	Proto-chromium.	4520·40	Proto-iron.
4294·20	Proto-titanium.	4522·80	Proto-iron.
4296·74	Proto-iron.	4534·14	Proto-titanium.

Wave-Length.	Origin.	Wave-Length.	Origin.
4558·83	Proto-chromium.	4824·33	Proto-chromium.
4584·02	Proto-iron.	4848·44	Proto-chromium.
4588·38	Proto-chromium.	4924·11	Proto-iron.
4629·52	Proto-iron.	5018·63	Proto-iron.

RIGELIAN (RIGEL).

3933·83	Proto-calcium.	4267·30	Carbon.
3964·88	Asterium.	4388·10	Asterium.
4026·34	Helium.	4471·65	Helium.
4128·20	Proto-silicium (II.).	4481·40	Proto-magnesium.
4131·04	Proto-silicium (II.).	4549·64	Proto-iron.
4143·92	Asterium.	4713·25	Helium.
4233·33	Proto-iron.		

CRUCIAN (BELLATRIX).

3933·83	Proto-calcium.	4388·10	Asterium.
3964·88	Asterium.	4471·65	Helium.
4009·42	Asterium.	4481·40	Proto-magnesium.
4026·34	Helium.	4567·90	Proto-silicium (III.).
4143·92	Asterium.	4574·79	Proto-silicium (III.).
4267·30	Carbon.	4713·25	Helium.

ALNITAMIAN (ε ORIONIS).

3933·83	Proto-calcium.	4143·92	Asterium.
4009·42	Asterium.	4388·10	Asterium.
4089·09	Proto-silicium (IV.).	4471·65	Helium.
4097·45	Nitrogen.	4567·90	Proto-silicium (III.).
4116·51	Proto-silicium (IV.).	4713·25	Helium.

ALGOLIAN (β PERSEI).

Wave-Length.	Origin.	Wave-Length.	Origin.
3933·83	Proto-calcium.	4233·33	Proto-iron.
4026·34	Helium.	4471·65	Helium.
4128·20	Proto-silicium (II.).	4481·40	Proto-magnesium.
4131·04	„ „		

MARKABIAN (α PEGASI).

3933·83	Proto-calcium.	4549·64	Proto-iron.
4385·55	Proto-iron.	4584·02	Proto-iron.
4481·40	Proto-magnesium.		

SIRIAN (SIRIUS).

3933·83	Proto-calcium.	4296·74	Proto-iron.
4045·98	Iron.	4303·34	Proto-iron.
4063·76	Iron.	4404·93	Iron.
4067·27	Proto-nickel.	4443·98	Proto-titanium.
4071·91	Iron.	4481·40	Proto-magnesium.
4131·04	Proto-silicium (II.).	4534·14	Proto-titanium.
4177·77	Proto-yttrium.	4558·83	Proto-chromium.
4215·70	Proto-strontium.	4924·11	Proto-iron.
4294·20	Proto-titanium.	5018·63	Proto-iron.

PROCYONIAN (PROCYON).

3944·16	Aluminium.	4163·82	Proto-titanium.
3961·67	Aluminium.	4202·20	Iron.
4030·92	Manganese.	4222·38	Iron.
4045·98	Iron.	4226·90	Calcium.
4063·76	Iron.	4254·51	Chromium.
4071·91	Iron.	4274·96	Chromium.
4077·89	Proto-strontium.	4294·20	Proto-titanium.

Wave-Length.	Origin.	Wave-Length.	Origin.
4383·72	Iron.	4501·45	Proto-titanium.
4404·93	Iron.	4558·83	Proto-chromium.
4415·29	Iron.	4584·02	Proto-iron.
4481·40	Proto-magnesium.		

ARCTURIAN (ARCTURUS).

4034·64	Manganese.	4494·74	Iron.
4071·91	Iron.	4525·31	Iron.
4202·20	Iron.	4554·21	Barium.
4254·51	Chromium.	4563·94	Proto-titanium.
4318·82	Calcium.	4611·47	Iron.
4369·94	Iron.	4703·18	Magnesium.
4404·93	Iron.	4783·61	Manganese.
4425·61	Calcium.	4859·93	Iron.
4484·39	Iron.	4861·53	Hydrogen.

APPENDIX.

In order to point out the importance of using simple lines, reference may be made to one or two cases where the use of complex and wrongly-identified lines has probably led to erroneous results.

In a paper* by Robert H. Baker on "The Radial Velocity of ϵ Ursæ Majoris," a list is given containing the lines which have been used for measurement in order to deduce the radial velocity of the star. Some of these are blends of two or more closely adjacent solar lines, and it would seem unfortunate that such lines should be selected for use in radial-velocity work, owing to the difficulty or impossibility of assigning the proper weights to the individual lines forming the blend, even if it be known exactly which lines form such blend. A good instance of this is the line 4198·837. Even with the dispersion of the Kensington two-prism spectrum — which is about four times that employed by Mr. Baker— this line is not separated into its component parts. It apparently coincides with the close group of four solar lines extending from 4198·402 to 4199·267, the most refrangible line being of unknown origin and the three others due to iron. It seems impossible to assign the exact wave-length to such a blend, and the value of the result obtained from measures on this line is discounted by the lack of knowledge as to the correct wave-length.

* "Publications of the Allegheny Observatory," vol. 1, No. 4.

In addition to these blends there appears to be one line which has had an erroneous identification and wave-length applied to it. This is the line 4352·083, which has been attributed to magnesium. There is no doubt that the *solar* line at that wave-length is really the counterpart of the magnesium *arc* line at the same wave-length. In the stellar line, however, there can be litttle doubt that the adjacent solar line 4351·930 is also involved and probably to a greater amount than the Mg. line 4352·083. This line (4351·930) has been ascribed by Rowland to Cr. only; but, from Kensington investigations on the proto-iron lines, the solar line is probably due in part to the proto-iron line 4351·930, which agrees in position exactly with the Cr. *arc* line. As there is abundant evidence that other enhanced iron lines and chromium arc lines occur in the spectrum of ϵ Ursæ Majoris it is a reasonable conclusion that the stellar line in question is a blend of the enhanced iron (4351·930), chromium arc (4351·930), and magnesium arc (4352·083) lines. Although it would be impossible to assign definitely the respective weights to these lines in forming the blend, it may be said that the enhanced lines of iron are in general considerably more prominent in ϵ Ursæ Majoris than either the chromium or magnesium arc lines.

Thus the evidence points to the fact that the real wave-length of the blend is something between 4351·930 and 4352·083 and probably approximates more closely to the former than to the latter. As the magnesium wave-length 4352·083 has been adopted by Mr. Baker for the stellar line, it would appear that the velocity determination from this line would be in error to the extent of from 5 to 8 k.m. per second.

In 1904 M. Tikhoff published a paper* on "The Radial Velocity of β Aurigæ." His results were based on measures of the displacement of the stellar lines 4481·3 and 4352—both of which he ascribed to magnesium—from their normal positions. The latter line is identical with that used by Mr. Baker in the case of ϵ Ursæ Majoris.

In β Aurigæ (which closely resembles the Sirian type) there is abundant evidence that this line is the analogue of the enhanced iron line λ 4351·930. The other well-enhanced lines of iron all occur in this stellar spectrum. On the other hand, there is little or no evidence for the identity of the stellar line with the magnesium line 4352·983, the equally strong *arc* line of that element at λ 4703·18 (this is stronger in the spark than 4352·083) being lacking in the stellar spectrum.

The difference of 0·15 tenth metres between the assumed and correct position of the normal stellar line would, if the results were based on observations of this line alone, necessarily affect the resulting velocity to the extent of 10 kilometres per second. From Tikhoff's paper it is impossible to say to what extent this line was used for his velocity determination, but it seems unfortunate that it should have been used at all, or, at any rate, that it should have been accepted as a magnesium line.

* Astr. Nach., No. 3916.

VI.

LINES OF UNKNOWN ORIGIN IN VARIOUS CELESTIAL SPECTRA.

INTRODUCTION.

During recent years much progress has been made in the identification of lines in celestial spectra with lines in the spectra given by known chemical elements under varying conditions of temperature and pressure. In the term "temperature" must be included—as was pointed out over 30 years ago*—the action of electricity.

There is still, however, a residuum of fairly prominent lines for which no satisfactory origin has yet been found by reference to terrestrial spectra. As the records which include some of these unorigined lines appear in various scientific journals, it has been thought advisable to compile a comprehensive list of such lines in order of wave-length, and at the same time indicate to which particular celestial spectrum they belong. Such a list is given at the end of the paper, and may prove useful to refer to in the event of any strange lines being found in laboratory spectra, with the object of possibly establishing their identity with lines in celestial spectra.

The records drawn on in obtaining this list are Rowland's "Tables of Solar Wave-Lengths," Campbell's publications on the spectra of bright-line stars† and nebulæ,‡ the Kensington publications on the chromosphere (supplemented by Dyson's) and corona,§ Pickering's lists for ζ Puppis‖ and H.P. 1311,¶ and the various Kensington records—published and unpublished—of stellar spectra.

Except in the case of the Fraunhoferic spectrum, the list includes only those unorigined lines which have an intensity of 3 or greater (maximum—except Rowland's Fraunhoferic, and Pickering's ζ Puppis—10) in the spectrum to which they individually belong. For the Fraunhoferic spectrum the number of lines of intensity 3 was considered to be too large for their inclusion in the table, and only lines of intensity 4 and upwards are recorded. In the nebula and bright-line-star records Campbell gives no numerical intensity, but indicates the brightest lines by a double cross. These are the only lines extracted from his records.

In some cases where the wave-lengths differ very little from each other it is quite possible that the numbers given may be slightly different wave-length determinations of the same line occurring in different spectra. These are indicated in the table.

* Roy. Soc. Proc., vol. 22, p. 372, 1874.
† Ast. and Ast. Phys., vol. 13, pp. 468–471.
‡ Ast. and Ast. Phys., vol. 13, pp. 494–501.
§ Phil. Trans., vol. 97, pp. 151, *et seq.*
‖ Annals Harv. Coll. Obs., vol. 28, Pt. II., p. 233.
¶ Annals Harv. Coll. Obs., vol. 28, Pt. 1., p. 48.

The breadth of the lines in the spectra of nebular and bright-line stars did not admit of Campbell giving his wave-lengths to an accuracy greater than that of the nearest tenth-metre. The wave-lengths of the lines in the ordinary stellar spectra, and in that of the chromosphere, are probably not in error to the extent of more than 0·2 tenth-metres.

It is, of course, possible and even probable that some of these lines may yet be accounted for by lines of known elements which only appear under conditions not yet attained in the laboratory. Perhaps the more probable explanation is that they belong to chemical elements not yet found terrestrially. If any spectra should be obtained in the laboratory, the lines of which adequately account for any of the celestial lines given in the list, it is quite probable that other weaker lines occurring in the same celestial spectrum, but not included in this list, will be traced to their true origins.

The crosses under the different headings indicate the celestial spectrum to which the various lines belong.

FAIRLY PROMINENT LINES IN CELESTIAL SPECTRA FOR WHICH NO TERRESTRIAL ORIGIN IS KNOWN.

Unoriginel Lines in Celestial Spectra.		Fraunhoferic Spectrum (Rowland).	Chromosphere (Kensington or Dyson).	Corona (Kensington).	Nebulæ (Campbell).	Bright Line Stars (Campbell).	Stellar Spectra (Kensington).					ζ Puppis (Pickering).	H.P. 1311 (Pickering).	Nova Persei Later Stages (Kensington).	Remarks.
λ	Intensity.						α Cygni.	ε Ursæ Majoris.	ε Orionis.	α Andromedæ.	θ Aurigæ.				
3860·0	2–3										×				Possibly identical lines in α Cygni and θ Aurigæ.
3860·1	3						×								
3868	10													×	
3911·4	3							×							
3938·2	3		×												
3938·55	4	×													Solar and stellar lines probably identical.
3938·6	3						×	×							
3943·9	4									×					
3945·2	3						×								
3952·3	3–4		×												
3954·3	3–4										×				
3968·35	6	×													
3968·89	6	×													
3970·01	8													×	Probably partly due to Hydrogen (Hε). Intensity much too high for that line alone.
3984·1	3–4									×					
3986·90	6	×													
3987·0	5			×											

Fairly Prominent Lines in Celestial Spectra for which no Terrestrial Origin is known *continued*

Unorigined Lines in Celestial Spectra.		Fraunhoferic Spectrum (Rowland).	Chromosphere (Kensington or Dyson).	Corona (Kensington).	Nebulæ (Campbell).	Bright-Line Stars (Campbell).	Stellar Spectra (Kensington).					ζ Puppis (Pickering).	H.P. 1311 (Pickering).	Nova Persei Later Stages) (Kensington).	Remarks.
λ	Intensity.						α Cygni.	ε Ursæ Majoris.	ε Orionis.	α Andromedæ.	θ Aurigæ.				
4021·6	3		×												
4024·6	3						×								
4026·0	8											×			
4057·67	7	×													
4059													×		
4067					×										Wright's λ 4068·8 ± ·5.
4069·7	4								×						Possibly compounded of Oxygen line 4070·1 and an unknown line.
4076·3	3										×				
4086·7	3		×												
4122·8	3							×							Probably identical lines in the chromospheric and stellar spectra.
4122·9	3–4						×								
4123·0	3		×												
4128·9	3							×							
4132·6	5							×							
4137·0	3									×					
4137·5	3		×												

| | | |

FAIRLY PROMINENT LINES IN CELESTIAL SPECTRA FOR WHICH NO TERRESTRIAL ORIGIN IS KNOWN—*continued.*

Unorigined Lines in Celestial Spectra.						Stella Spectra (Kensington).								Remarks.
λ	Intensity.	Fraunhofer Spectrum (Rowland).	Chromosphere (Kensington or Dyson).	Corona (Kensington).	Nebulæ (Campbell).	Bright Line Stars (Campbell).	α Cygni.	ε Ursæ Majoris.	ε Orionis.	α Andromedæ.	θ Aurigæ.	γ Puppis (Pickering).	H.P. 1311 (Pickering).	Nova Persei Later Stages (Kensington).	
4496·8	3		×												Evershed and Dyson give this line as Cr., but in the absence of equally strong Cr. lines this origin is doubtful.
4509						×									
4542						×									
4542·4	10											×			Probably identical line (one of new hydrogen series) in each spectrum.
4544	3												×		
4568·5	3			×											
4600·8	3		×												
4650														×	Possibly identical line in each spectrum.
4652						×									
4654·6	3								×						
4663					×										
4687	2–3		×												Probably identical line in each of these spectra and also identical with the first line in the principal series of hydrogen. (*See* Roy. Soc. Proc., vol 74, p. 546.)
4688					×	×						×			
4699·51	4	×													
4700·34	4	×													
4720	6													×	
4731·4	3–4		×												
4731·7	3–4						×								

4743					×									Wright's λ 4740 ± 1 0.
4757·5	3		×											
4762·0	4		×											
4811·0	3		×											
4959					×									Wright's λ 4959·05.
5007					×									Wright's λ 5006·89.
5303·7	10			×										

8371